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JULES CÉSAR JANSSEN

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La carrière scientifique de Janssen a été faite plutôt dans des observatoires temporaires installés dans quelque partie reculée du globe et avec un matériel facilement transportable, que dans des établissements fixes pourvus de grands instruments. C'est que Janssen était, avant tout, un missionnaire de la science, toujours prêt à se dépenser en nouveaux efforts pour organiser et mener à bien une expédition. Son esprit d'entreprise aimait ces voyages où il était soutenu par la pensée de se dévouer plus complètement à la science qu'en travaillant paisiblement dans son laboratoire.

Les principales missions remplies par Janssen avaient pour objet l'observation d'un phénomène visible seulement en un point determiné du globe, ou la recherche d'un ciel favorable à certaines expériences délicates. Mais, dans l'un et l'autre cas, Janssen poursuivait des expériences qui avaient un but commun car son œuvre présente une unité remarquable. On peut dire, en effet, que toutes ses études ont porté sur l'absorption sélective des radiations par les gaz. Sa vocation pour ce genre de recherches a été déterminée par les découvertes de Kirchhoff et Bunsen sur les spectres d'absorption aussi les premières expériences spectroscopiques de Janssen datent-elles de 1862, c'est-à-dire peu de temps après que les physiciens allemands eussent fait connaître leurs travaux.

Janssen a étudié l'absorption des radiations solaires produites par l'atmosphère même du soleil, d'une part, et par l'absorption de

notre atmosphère terrestre, d'autre part. C'est en observant les enveloppes gazeuses du soleil, qui sont seulement visibles pendant les courts instants que dure une éclipse totale, qu'il a réalisé la première partie de ce programme, et c'est en entreprenant ses travaux classiques sur les raies telluriques qu'il a réalisé la seconde. Nous allons suivre Janssen dans ses recherches sur ces deux ordres de questions.

L'éclipse totale du soleil de 1868 était impatiemment attendue par Janssen, car elle allait lui fournir l'occasion d'étudier, pour la première fois, au spectroscope, les atmosphères solaires. Pour se préparer, en quelque sorte, à l'observation de cet important phénomène, Janssen demanda à être envoyé à Trami, en Italie, pour observer l'éclipse annulaire du soleil de 1867. Son but était d'étudier le spectre de l'anneau solaire, pour y découvrir, si possible, des traces de l'absorption produite par l'atmosphère solaire. Mais le spectre de l'anneau se montra identique au spectre du centre du soleil.

Pendant la même éclipse, il a cherché aussi à voir la couronne, sans pouvoir y parvenir.

Mais l'éclipse de 1868 lui réservait l'honneur de faire une grande découverte. On sait qu'après avoir vu, dans son spectroscope, les raies brillantes des protubérances qui apparurent pendant la totalité, il n'hésita pas à affirmer, avec l'autorité que lui donnait sa grande compétence en spectroscopie, qu'il pourrait revoir ces raies en dehors des éclipses. Dès le lendemain de l'éclipse, il eut la joie de voir se réaliser ses prévisions.

On sait aussi que la même découverte fut faite indépendamment en Angleterre, par Sir Norman Lockyer, aussi les noms de ces deux savants sont-ils demeurés associés à cette application si féconde de l'analyse spectrale. Janssen paraît avoir entrevu, dès le premier jour, toute l'importance de la découverte qu'il venait de faire. On en trouve la preuve dans une lettre qu'il adressait à sa mère et où il dit: "Je lis dans un livre jusqu'ici fermé à tous et dans lequel on ne pouvait jeter que quelques courts regards pendant les éclipses."

Les résultats obtenus pendant l'éclipse de 1868, étaient trop beaux pour que Janssen se soit arrêté dans la voie qu'il venait d'ouvrir aux astronomes. Aussi avait-il décidé d'aller en Algérie à l'occasion

de l'éclipse totale du mois de décembre 1870. Cette éclipse ne put malheureusement pas être observée à cause du mauvais temps, mais elle fournit à Janssen l'occasion de donner à la science un témoignage éclatant de dévouement. Enfermé, en effet, dans Paris par le siège, Janssen ne craignit pas d'affronter les risques d'un voyage en ballon pour franchir les lignes ennemies. Cet acte de courage fit plus pour sa popularité que sa belle découverte du spectre des protubérances, et, pour le public, qui voyait encore à cette époque un vrai danger à affronter la route des airs, cette manière audacieuse de s'échapper de la capitale assiégée, donna la mesure du dévouement dont Janssen était capable pour la science. Janssen garda de ce voyage aérien exécuté dans de si périlleuses conditions, un amour sincère pour l'aérostation. Il eut souvent l'occasion de prouver l'intérêt qu'il portait à cette science en donnant de précieux conseils aux aéronautes, en acceptant de présider diverses sociétés aéronautiques et en donnant une large hospitalité, à Meudon, à des congrès internationaux d'aérostation.

Un an après l'éclipse de 1870, une autre éclipse devait être visible aux Indes et à Java. Janssen n'eut garde de manquer cette nouvelle occasion d'étudier les atmosphères solaires. Un examen attentif des conditions météorologiques des diverses localités visitées par l'éclipse lui fit adopter une station située aux Indes, dans les Neelgheries; les évènements lui donnèrent raison, car il aurait été difficile d'observer l'éclipse dans de meilleures conditions atmosphériques. Cette fois l'attention de Janssen se porta principalement sur la couronne. Il observa, dans le spectre de la couronne, non seulement la raie verte, dont la présence avait déjà été signalée, mais aussi les raies noires du spectre solaire démontrant ainsi qu'une partie de la lumière de la couronne est de la lumière solaire réfléchie, ce qui tend à prouver que l'atmosphère coronale n'est pas exclusivement gazeuse, mais comprend aussi des particules solides ou liquides.

En 1875, nous retrouvons Janssen observant une éclipse dans la presqu'île de Malacca au retour d'un vovage au Japon.

Puis, en 1883, sans craindre les fatigues d'un voyage fait dans des conditions pénibles, il se rend à l'île Caroline, en plein océan Pacifique, pour observer une éclipse totale de soleil, remarquable par sa grande durée. Grâce aux plaques photographiques au gela-

tino-bromure d'argent, qui venaient d'être inventées, le phénomène put être photographié dans des conditions très variées, ce qui lui permit de rapporter des documents du plus haut intérêt au sujet de l'étendue de la couronne solaire.

Avant de terminer sa carrière, Janssen voulut encore observer une dernière fois un de ces beaux phénomènes qui eurent toujours pour lui tant d'attrait. Aussi, en 1905, malgré son âge avancé, il se rendit en Espagne, pour se donner le plaisir de contempler une éclipse en curieux plutôt que de l'observer en astronome.

Nous venons de voir ce qu'a fait Janssen pour l'étude des enveloppes gazeuses du soleil par l'application du spectroscope à l'observation des éclipses. Nous allons passer en revue maintenant ce qu'il a fait pour l'étude de l'absorption des radiations solaires par notre propre atmosphère.

Les premières expériences spectroscopiques de Janssen se rapportent à l'étude des bandes noires qui apparaissent dans le spectre du soleil à l'horizon et qui avaient été signalées par Sir David Brewster, sans que ce dernier ait reconnu leur véritable structure et la cause de leur formation. Par des observations faites à Rome en 1862–1863, Janssen découvrit que les bandes de Brewster étaient résolubles en raies, et il prouva que l'origine de ces raies devait être attribuée à l'absorption sélective des rayons solaires produites par les gaz de notre atmosphère. On reconnut plus tard que c'était l'oxygène de l'atmosphère qui donnait naissance à ces raies A, *a*, et B du spectre solaire. Mais l'oxygène de notre atmosphère n'est peut-être pas la seule cause de la production de ces raies; s'il existe, en effet, de l'oxygène dans les enveloppes gazeuses du soleil, l'atmosphère solaire pourrait aussi avoir sa part dans la production du phénomène. Or, au point de vue de la théorie du soleil, il est de la plus haute importance de savoir si l'oxygène coexiste avec l'hydrogène dans l'atmosphère solaire. Janssen attachait à cette question de la présence de l'oxygène dans le soleil une importance capitale. Aussi, a-t-il cherché, par toutes les manières possibles, à décider si les raies A, *a*, B du spectre solaire ont une origine à la fois terrestre et solaire ou si elles sont produites uniquement par notre atmosphère. Pour résoudre ce problème, il produisit dans son laboratoire ces raies d'absorption pour se rendre compte si une colonne d'oxygène

équivalente à l'oxygène contenu dans notre atmosphère pouvait produire des raies de même intensité que celles que nous observons dans le spectre solaire. Dans le même ordre d'idées, il observa le spectre d'une source lumineuse assez distante pour que l'air interposé puisse produire une absorption équivalente à celle de l'atmosphère tout entière aux différentes hauteurs du soleil au-dessus de l'horizon. Puis, nous le verrons faire en quelque sorte la contre expérience et chercher si, en diminuant suffisamment l'action absorbante de l'air interposé, il parviendrait à faire disparaître les raies en question.

L'étude des spectres d'absorption des gaz a fait l'objet de recherches trés approfondies de la part de Janssen. Il examinait, au spectroscope, la lumière d'une source à spectre continu qui avait traversé des tubes contenant des gaz sous diverses pressions et à diverses températures. Son laboratoire, installé dans les anciennes écuries du château de Meudon, lui permettait de disposer de tubes dont la longueur atteignait 60 mètres. Les expériences ont surtout porté sur l'oxygène. En faisant varier la pression du gaz dans le tube, il faisait apparaître à volonté les raies d'absorption de l'oxygène et notamment la raie B. Ces expériences montrèrent qu'une certaine raie d'absorption, B par example, apparaissait toujours lorsque le produit de la longueur du tube par la pression du gaz atteignait la même valeur.

Mais ces expériences sur les raies d'absorption de l'oxygène, ont conduit Janssen à une observation remarquable qui demanderait à être répétée avec les moyens perfectionnés dont dispose la physique moderne. Janssen découvrit, qu'en outre des raies telluriques, le spectre d'absorption de l'oxygène présentait, dans certaines conditions, un système de bandes difficiles à résoudre en raies et dont la production est régie par une toute autre loi que celle que nous avons indiqué plus haut pour les raies telluriques. Ces bandes font leur apparition lorsque le produit de la longueur du tube par le carré de la pression, atteint une certaine valeur. Cette loi trouva une éclatante confirmation, lorsque M. Olszewski étudia le spectre d'absorption de l'oxygène liquide. Il reconnut que les bandes de Janssen apparaissaient lorsque la couche de l'oxygène absorbante atteignait l'épaisseur indiquée par la loi du carré des pressions.

Janssen a aussi confirmé sa loi d'une autre manière: il a calculé que, lorsque le soleil était à une hauteur au-dessus de l'horizon inférieur à 4°, l'épaisseur de la couche d'air traversée par les rayons solaires était suffisante pour donner naissance aux bandes. Or, s'étant rendu dans le Sahara, afin de pouvoir observer le soleil à son lever, Janssen reconnut la présence des bandes dans le spectre solaire, tant que le soleil n'avait pas atteint précisément cette hauteur de 4°.

Ces résultats remarquables peuvent avoir pour la physique moléculaire des conséquences théoriques dont l'importance ne paraît pas avoir été suffisamment appréciée jusqu'ici.

Dans ses expériences de laboratoire à Meudon, Janssen ne se contenta pas de faire varier la pression des gaz et la longueur des colonnes traversées par la lumière; il porta aussi les gaz à des températures élevées afin de se rapprocher des conditions où ils se trouvent dans le soleil. Par des procédés électriques, très remarquables pour l'époque où ils ont été imaginés, Janssen a pu porter des gaz à des températures atteignant 900° C. Aucun phénomène nouveau ne s'est manifesté à cette température, mais la visibilité des raies d'absorption avait considérablement augmentée.

L'absorption produite par la vapeur d'eau fut aussi étudiée dans le laboratoire de Meudon. Déjà, à l'origine de ses études de spectroscopie, en 1867, Janssen avait observé le spectre d'absorption de la vapeur d'eau en faisant passer des rayons lumineux au travers d'un tube de 37 mètres de long rempli de vapeurs. Cette mémorable expérience faite à l'usine à gaz de la Villette, avait permis à Janssen de relever les positions des principales raies d'absorption de la vapeur d'eau. Mais ces expériences furent reprises dans de meilleures conditions, avec des instruments perfectionnés, dans le laboratoire de Meudon, en 1887.

L'étude du spectre de la vapeur d'eau avait pour but de rechercher si l'eau existe dans les atmosphères des planètes. Cette question, d'une importance capitale pour l'astronomie physique, a toujours beaucoup préoccupé Janssen. Dès 1867, sur l'Etna, et en 1869 sur l'Himalaya, Janssen avait observé le spectre de Mars pour chercher à y reconnaître les raies *a* de la vapeur d'eau. A cet effet, il avait comparé l'intensité des raies *a* dans le spectre de Mars et dans le spectre de la lune, ces deux astres étant à la même hauteur au-dessus

de l'horizon. Janssen avait conclu de ses observations que le spectre de Mars donnait des signes évidents de la présence de la vapeur d'eau dans l'atmosphère de la planète et il considérait ses expériences comme assez décisives pour maintenir ses conclusions, lorsqu'en 1895, Campbell annonça que les grands instruments de l'Observatoire de Lick ne lui avaient pas permis de trouver des traces de vapeur d'eau sur Mars. Or, tout dernièrement, Mr. Slipher de l'Observatoire Lowell a obtenu des photographies sur lesquelles les raies de la vapeur d'eau paraissent plus intenses dans le spectre de Mars que dans le spectre de la lune. Cette observation importante vient confirmer, en tous points, les conclusions de Janssen.

Mais revenons aux expériences de Janssen sur l'oxygène. Après avoir étudié, dans son laboratoire, les conditions de la production des bandes d'absorption de l'oxygène, Janssen voulut obtenir ces bandes en interposant, entre la source lumineuse et l'observateur, une couche d'air suffisante pour leur donner naissance. Or, en 1889, la Tour Eiffel venait d'être construite et un puissant phare électrique établi sur son sommet pouvait être dirigé vers l'observatoire de Meudon. De plus, la distance qui séparait la tour de l'observatoire étant de 7.7 kilomètres, la lumière, avant d'arriver à l'observateur, avait à traverser une colonne d'air précisément équivalente, au point de vue de l'absorption, à notre propre atmosphère. Dans ces conditions, les raies d'absorption de l'oxygène apparaissaient avec la même intensité que dans le spectre solaire, ce qui apportait une confirmation de l'origine exclusivement terrestre de ces raies.

Cette expérience de la Tour Eiffel pouvait être considérée comme la répétition d'une autre expérience ingénieuse réalisée par Janssen, dès 1864, sur les bords du lac de Genève. Un feu de bois fut allumé à Nyon, sur l'une des rives du lac; or, tandis qu'à une faible distance le spectre de ce foyer était continu, il présentait, lorsqu'on l'observait de Gènêve, à une distance de 21 kilomètres, les raies telluriques et de la vapeur d'eau.

Nous avons déjà dit que Janssen, non content d'avoir pu produire artificiellement, en quelque sorte, les raies d'absorption de l'oxygène, avait voulu faire la contre expérience, et s'assurer que les raies telluriques du spectre solaire tendaient bien à disparaître lorsqu'on s'élevait dans l'atmosphère, c'est-à-dire au fur et à mesure

que diminue la couche d'air interposée entre le soleil et l'observateur. C'est pour constater ce fait que Janssen entreprit plusieurs ascensions en montagne: au Faulhorn, d'abord, en 1864, puis au Pic du Midi, et plus récemment enfin, au Mont Blanc. Dans une première ascension aux Grands Mulets, en 1888, il constata nettement que les raies du groupe B étaient moins intenses à une altitude de 3,000 mètres qu'elles ne le sont à Meudon, et dans des ascensions au sommet, en 1893 et en 1895, il crut voir que les derniers doublets de B disparaissent complètement. Sa claudication l'empêchant de marcher, il dut pour atteindre le sommet du Mont Blanc, se faire porter sur une sorte de brancard, ou se faire traîner dans un traîneau, ce qui a rendu ces ascensions singulièrement difficiles. Janssen rapporta de ses expéditions au Mont Blanc la conviction qu'un observatoire, construit au sommet même de la célèbre montagne, rendrait certainement d'importants services à la science et contribuerait à résoudre bien des problèmes d'astronomie, de météorologie et de physiologie. L'astronome, en s'élevant à ces altitudes, s'affranchirait de ce que l'on a appelé "la vase atmosphérique," et la lumière des astres lui parviendrait moins déviée et moins diffusée; le météorologiste, placé au sein même de l'atmosphère, surprendrait les secrets de la formation des nuages; le physiologiste enfin pourrait étudier dans ce laboratoire élevé les conditions de la vie sous une pression moitié moindre que dans la plaine.

La création de l'Observatoire du Mont Blanc une fois décidée, il a fallu à Janssen une énergie peu commune pour mener à bien son projet. Grâce à sa parole convaincante, il réussit à réunir les fonds nécessaires pour la construction de l'édifice, puis, bravant les critiques, il posa hardiment la construction sur la neige, au sommet même du Mont Blanc, pour dominer, de cette position culminante, tout le massif des Alpes. C'est peut-être dans cette entreprise de la création de l'Observatoire du Mont Blanc que Janssen donna le mieux la mesure de l'énergie, de la ténacité et de l'audace dont il était capable. N'est-ce pas, d'ailleurs, à propos de la réalisation de cette œuvre qu'il a dit: "J'ai toujours pensé qu'il n'est bien peu de difficultés qui ne puissent être surmontées par une volonté forte et une étude suffisamment approfondie." Dans les dernières années de sa vie, Janssen avait pour l'Observatoire du Mont Blanc, la sollici-

tude d'un père pour son enfant. Chaque année il se plaisait à donner des conseils aux observateurs qui se proposaient de faire l'ascension du géant des Alpes pour entreprendre quelque recherche nouvelle; il organisait les expéditions dans les moindres détails aidé dans cette tâche par Madame et Mademoiselle Janssen.

Janssen était un enthousiaste de la montagne, il ne cessait de louer ses bienfaits et se plaisait de répéter aux ascensionnistes, cette phrase de notre grand physicien Foucault, "la montagne fait l'homme, la ville le consomme."

Nous venons de voir par quel enchaînement d'idées Janssen a été conduit à observer des éclipses de soleil, à faire des expériences de laboratoire, et à analyser la lumière solaire dans de hautes stations, pour étudier l'absorption produite par les enveloppes gazeuses du soleil et par notre propre atmosphère. En dehors de ces études, Janssen s'intéressa à d'autres questions qui lui offrirent l'occasion de satisfaire ses goûts pour les voyages. En 1874 et 1882, il fut le chef tout indiqué de missions envoyées par la France pour observer les passages de Vénus sur le soleil. C'est pour étudier ces phénomènes qu'il imagina le révolver photographique. Cet instrument permettait de prendre une série de photographies à de courts intervalles afin de décider à quel instant précis avaient lieu les contacts de la planète avec le disque solaire. Le révolver photographique a été le précurseur des appareils de M. Marey pour l'étude des mouvements des animaux et c'est aussi sur son principe que sont construits les cinématographes actuels.

L'étude des volcans, et notamment l'analyse spectrale des gaz qui s'échappent de leurs cratères, attira l'attention de Janssen et fut l'occasion de voyages au Santorin, aux Açores, aux îles Sandwich et tout dernièrement encore au Vésuve.

Enfin, il profita souvent de ses voyages pour déterminer les éléments magnétiques du globe. C'est ainsi que son premier voyage scientifique a eu pour objet de reconnaître la position de l'équateur magnétique au Pérou; il fit ensuite, aux Açores, des observations magnétiques appliquées à la géologie et on lui doit aussi des déterminations de l'équateur magnétique aux Indes et dans la presqu'île de Malacca.

Mais ses nombreux voyages ne suffisaient pas à absorber toute

son énergie. Entre temps, il fonda, en 1874, l'observatoire de Meudon, et, en outre de ses travaux sur les spectres d'absorption des gaz, dont nous avons parlé, il s'y occupa de photographie et notamment de photographie solaire. Janssen a été un des premiers à pressentir les services que pourrait rendre la plaque sensible, dans les observatoires et il résuma d'un mot le rôle prépondérant que la photographie était appelée à jouer dans les sciences d'observation en disant que la plaque photographique était la véritable rétine du savant.

Aidé de M. Arents, d'abord, puis par M. Pasteur, il obtint, dans son observatoire de Meudon, cette remarquable série de photographies solaires dont les épreuves les plus caractéristiques ont été réunies dans un atlas et constituent un véritable monument élevé à l'histoire du soleil. Ces photographies faites spécialement en vue de l'étude physique de la surface solaire, présentent les détails les plus délicats de la photosphère. En les examinant attentivement, Janssen a découvert que la surface du soleil présente une texture particulière qu'il a désignée sous le nom de réseau photosphérique. La production de ce réseau fut attribuée tout d'abord à des déplacements réels des granulations de la photosphère, mais on se demanda plus tard si l'on ne devait pas en chercher l'origine dans des réfractions irrégulières produites soit par notre atmosphère, soit par l'atmosphère du soleil.

La photographie a toujours été en honneur à l'observatoire de Meudon, et, non content de l'appliquer à des observations qualitatives, Janssen voulut s'en servir pour faire des observations quantitatives. Aussi lui doit-on de nombreuses expériences de photométrie photographique, et notamment des déterminations des éclats relatifs du soleil et des étoiles. Il a été un des premiers à faire usage, pour des mesures photométriques, de disques stellaires obtenus en dehors du foyer. Mais Janssen avait, pour la photographie, une prédilection qui s'étendait à toutes les applications de cette science et il en donna la preuve en acceptant de présider de nombreuses réunions de sociétés et de congrès photographiques.

Janssen était, avant tout, un observateur et un homme d'action. Il ne s'est pas laissé tenter par le désir de donner son nom à une théorie du soleil; il savait qu'il est plus utile de récolter des observa-

tions que d'édifier des théories sur des faits insuffisamment démontrés. Mais il ne faudrait pas en conclure que l'esprit de Janssen restait indifférent aux spéculations. Dans nombre de ses écrits on trouve une élévation de pensées qui témoigne de son esprit philosophique et de son souci de remonter à l'origine des choses.

Né en 1824, Janssen ne s'adonna complètement à la science que vers 1860 à l'âge de 36 ans, mais sa carrière scientifique fut néanmoins aussi longue que celle de bien des savants, car il conserva tard toutes ses aptitudes pour le travail et s'éteignit le 23 décembre dernier, après avoir atteint sa 84^{e} année.

SOLAR VORTICES[1]

BY GEORGE E. HALE

The problem of interpreting the complex solar phenomena recorded by the spectroheliograph has occupied my attention since the first work with this instrument in 1892. The measurement of the daily motions in longitude of the calcium flocculi has led to several new determinations of the solar rotation,[2] and their areas, measured by a photometric method, are being used as an index to the solar activity. Various investigations on their forms at different levels,[3] their distribution in latitude and longitude, etc., have also been carried out. But the failure of the calcium flocculi to indicate the existence of definite currents in the solar atmosphere has been a disappointment.

The hydrogen flocculi, though occupying the same general regions on the sun's disk, are distinguished from those of calcium by several striking peculiarities. In the first place, most of them are dark, while the corresponding calcium (H_2) flocculi are bright. Secondly, as I have recently shown,[4] they seem to obey a different law of rotation, in which the equatorial acceleration (better, the polar retardation), shared by the spots, faculae, and calcium flocculi, does not appear. A third peculiarity, briefly mentioned in previous papers, is clearly visible on many hydrogen photographs. It is a decided definiteness of structure, indicated by radial or curving lines, or by some such distribution of the minor flocculi as iron filings present in a magnetic field (see, for example, *Astrophysical Journal*, Vol. XIX, Plates X and XII). First recognized at the beginning of our work with the hydrogen lines in 1903, this suggestive structure has repeatedly shown itself on the Mount Wilson negatives. But its

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 26.

[2] Hale and Fox, *The Rotation of the Sun, as Determined from the Motions of the Calcium Flocculi.* Carnegie Institution (in press); Fox, *Science*, April 19, 1907; Hale, *Contributions from the Mount Wilson Solar Observatory*, No. 25; *Astrophysical Journal*, **27**, 219, 1908.

[3] Hale and Ellerman, *Publications of the Yerkes Observatory*, Vol. III, Part I.

[4] Hale, *Contributions from the Mount Wilson Solar Observatory*, No. 25; *Astrophysical Journal*, **27**, 219, 1908.

true meaning did not appear until the results described in this paper had been obtained.

With the Rumford spectroheliograph the hydrogen lines $H\beta$, $H\gamma$, and $H\delta$ were used. Certain differences between the photographs, which seemed to depend upon the wave-length, pointed to the desirability of trying $H\alpha$. But plates sufficiently sensitive to red light were not to be had at that time, and therefore the experiment was postponed.

The extreme sensitiveness in the red of plates prepared according to a formula due to Wallace[1] now renders it a simple matter to photograph the sun with $H\alpha$. Some preliminary work with the spectroheliograph attachment of the 30-foot Littrow spectrograph of the tower telescope, in which I had the assistance of Mr. Adams, indicated that bright flocculi are more numerous and extensive when photographed with $H\alpha$ than when $H\delta$ is used. I then tried $H\alpha$ with the five-foot spectroheliograph of the Snow telescope, and immediately obtained excellent results. The images were stronger and of much better contrast than those given by $H\delta$. Moreover, the curved and radial structure surrounding sun-spots was so striking as to lead to the hope that important advances might be expected to follow from the systematic use of the $H\alpha$ line.

On account of the difference in curvature of $H\alpha$ and $H\delta$, these preliminary photographs made with $H\delta$ slits showed only a very narrow zone of the solar image. A new pair of slits, of suitable curvature for $H\alpha$, was accordingly made for the five-foot spectroheliograph, and as soon as these were ready I completed the adjustments of the instrument, with Mr. Ellerman's assistance, and made comparative photographs of the entire disk with $H\alpha$ and $H\delta$. The differences exhibited by these plates are very marked. For example, a long dark flocculus, strongly shown by $H\alpha$, is represented on an $H\delta$ photograph by only a few of its most intense parts. In the case of bright flocculi, the differences are even more conspicuous, large luminous areas shown by $H\alpha$ being absent from the $H\delta$ plates. To eliminate errors arising from possible changes on the sun between exposures, the photographs were taken in rapid succession, an $H\alpha$ plate between two of $H\delta$. In this way all doubts as to the genuine-

[1] *Astrophysical Journal*, **26**, 299, 1907.

ness of the observed differences were removed. Plate III illustrates the general character of these differences, concerning the cause of which we may now inquire.

It naturally occurred to me that photographs of a prominence at the sun's limb, taken with the various hydrogen lines, would be likely to throw light on the question. Mr. Ellerman accordingly made a series of photographs of a prominence, using the lines $H\alpha$, $H\beta$, $H\gamma$, and $H\delta$. The fall of intensity toward the violet was very marked, the faint $H\delta$ image bringing out only the brightest parts of the prominence as photographed with $H\alpha$ (Figs. 2 and 3, Plate IV). $H\beta$ and $H\gamma$ gave intermediate results, resembling those obtained with $H\delta$.

It thus seems probable that the marked intensity of the $H\alpha$ flocculi results from the great strength of the $H\alpha$ line in the chromosphere and prominences. $H\delta$ is strong enough in the middle and sometimes in the upper chromosphere and in the lower parts of bright prominences to show the hydrogen in these regions when projected on the disk. $H\alpha$, being much more intense, renders visible a higher region of the solar atmosphere, including the upper chromosphere and bright prominences. Whether these are to appear as bright or dark flocculi, when photographed against the disk, probably depends primarily upon their temperature, though the conditions may not be such as to permit the direct application of Kirchhoff's law.

But the photographs bring out a second fact of interest. Although, as has been stated, the flocculi are generally stronger on the $H\alpha$ plates, it cannot be said that these $H\alpha$ images are merely intensified $H\delta$ images. For there is an important point of difference: dark $H\delta$ flocculi are sometimes replaced on the $H\alpha$ plates by bright flocculi or by apparently neutral spaces. The condition of the hydrogen in such regions thus appears to be the same as in certain stars, whose spectra show $H\alpha$ bright and the more refrangible hydrogen lines dark.[1]

The importance of continuing the work of photographing the sun

[1] I leave for future consideration the question whether the neutral regions on the $H\alpha$ plates are to be regarded as bright flocculi of reduced intensity. It will also be important to determine whether Kayser's explanation of the appearance in a stellar spectrum of both bright and dark hydrogen lines (*Astrophysical Journal*, **14**, 313) will apply to solar phenomena.

PLATE III

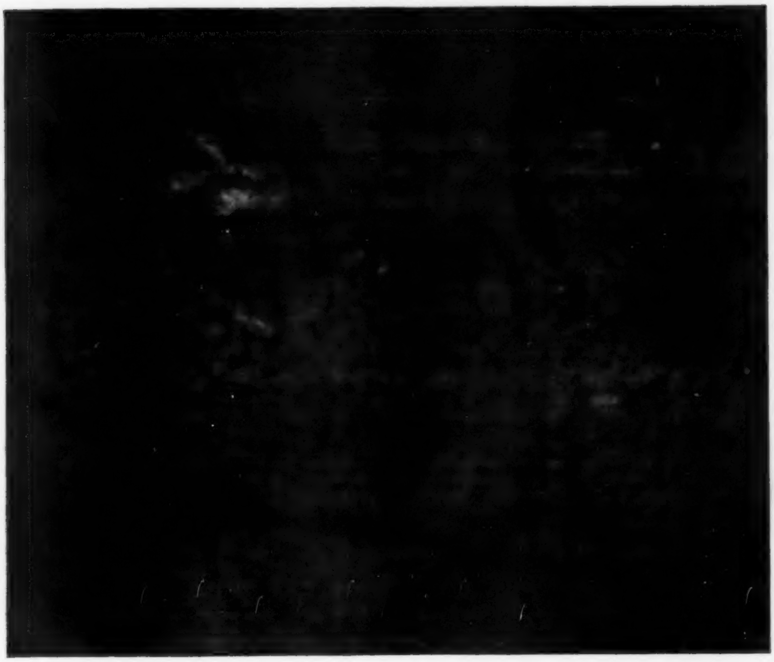
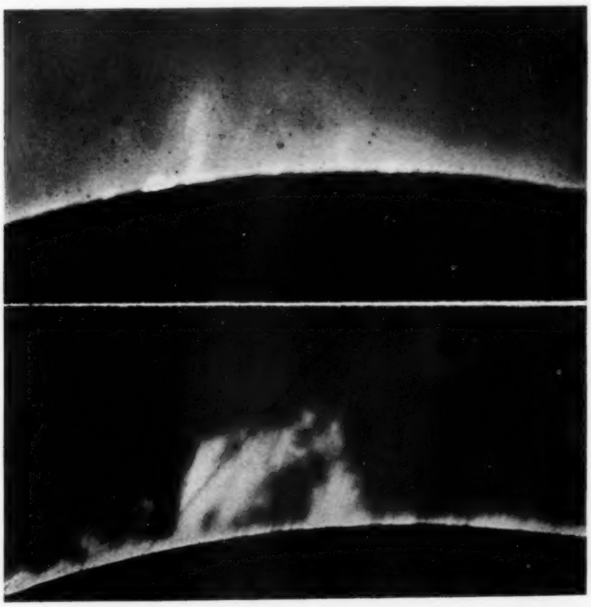


FIG. 1.—HYDROGEN FLOCCULI, PHOTOGRAPHED WITH THE *Hα* LINE
1908, May 1, $4^h\,48^m$ P. M. Scale: Sun's Diameter = 0.2 Meter

FIG. 2.—HYDROGEN FLOCCULI, PHOTOGRAPHED WITH THE *Hδ* LINE
1908, May 1, $5^h\,07^m$ P. M. Scale: Sun's Diameter = 0.2 Meter

PLATE IV

FIG. 1.—PROMINENCES AT EASTERN LIMB OF THE SUN
1908, May 26, $6^h\ 38^m$ A. M. Scale: Sun's Diameter = 0.3 Meter



FIGS. 2 AND 3.—PROMINENCES PHOTOGRAPHED WITH $H\delta$ (FIG. 2) AND $H\alpha$ (FIG. 3)
1908, April 3. Scale: Sun's Diameter = 0.3 Meter

with $H\alpha$ was obvious, and I immediately modified the daily programme of observations with this object in view. In the photography of the chromosphere and prominences at the limb, $H\alpha$ was substituted for the H line of calcium, since it was found to give stronger and sharper negatives. For the disk $H\alpha$ was adopted in place of $H\delta$, though work was continued with the latter line long enough to secure a series of comparative photographs. Later, as more $H\alpha$ plates were needed, the daily series of photographs with the iron line λ 4046 was discontinued, and all of the observing time of the Snow telescope in the morning devoted to $H\alpha$ work.[1] In the afternoon this line is also used most of the time, though one plate is made with H_1 and one with H_2 of calcium.

A serious difficulty at once presented itself. Previously only a few photographs had been taken during each of the best observing periods, which last less than two hours in the early morning and late afternoon. Between exposures the mirrors were shielded from sunlight, and electric fans kept a continuous blast of air directed upon them. Even with these precautions there would frequently be a marked change of focal length during an exposure lasting four minutes. The distortion of the mirrors increased during the observations and strong evidences of astigmatism often appeared before they were completed. Except for occasional eruptions, the calcium, iron, and $H\delta$ flocculi change rather slowly in form, and one or two photographs taken daily with each line sufficed for the investigations in progress. In the case of $H\alpha$ it seemed probable that many photographs, separated by short time-intervals, would be needed to register the phases of rapidly changing phenomena. This would mean almost uninterrupted exposure of the mirrors to sunlight, and such serious distortion that the astigmatism would ruin the photographs.

At this point experience with the tower telescope came in to good advantage. The very thick mirrors used with this instrument are not appreciably distorted in sunlight.[2] Hence it seemed probable that by reducing the aperture of the Snow telescope mirrors the increase in their relative thickness would relieve the difficulty. I

[1] Except the short interval required to obtain a direct photograph.

[2] Hale, *Contributions from the Mount Wilson Solar Observatory*, No. 23; *Astrophysical Journal*, **27**, 204, 1908.

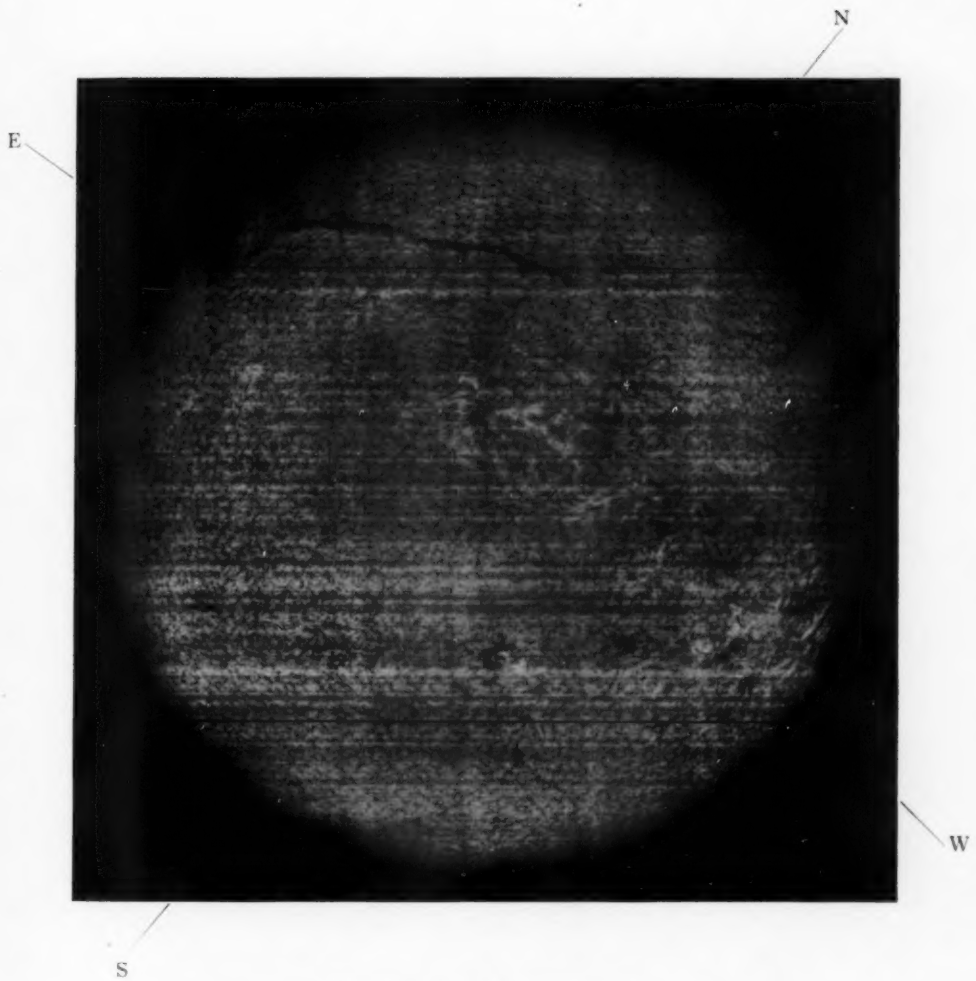
therefore commenced a series of experiments with different apertures, and finally adopted a 15-inch (38 cm) diaphragm for the coelostat in place of the full aperture of 30 inches (76 cm). With this the focal length does not ordinarily change perceptibly during a single exposure. When the mirrors are in sunlight, with very brief interruptions, during a period of an hour, the focal length gradually increases, but the effect of astigmatism is hardly appreciable.

In the work with $H\delta$, the hydrogen flocculi could not be photographed with sufficient contrast unless the very slow "Process" plates (also used for H_1 and H_2) were employed. These plates gave excellent results with $H\alpha$, but could not be used after the aperture had been reduced to 15 inches without undue increase of exposure time. Hence it was necessary to substitute for them Seed's "Gilt Edge" plates, which fortunately serve very well with this line. The first experiments with $H\alpha$ were made about the middle of March. On March 28 the new slits were in place, and the first photographs of the entire disk were obtained. During April the weather was not very favorable, but on April 29 and 30 Mr. Ellerman, then in charge of the routine work with the five-foot spectroheliograph, secured some remarkably fine negatives. The one taken on April 30 is reproduced in Plate V. Apart from the whirls, which may be seen to better advantage in Plates VI and VII, this photograph shows in projection an enormous prominence in the southern hemisphere. This also appears, though much less satisfactorily, on the $H\alpha$ photograph of May 1, and may be traced on the $H\delta$ photograph of the same date (Plate III).

But in spite of its great intensity and length, this prominence is of minor interest in comparison with the structure shown in Plates VI and VII. This is so definite in form and so unmistakable in character as to satisfy the hopes aroused by the earlier photographs. It seems evident, on mere inspection of these photographs, that sun-spots are centers of attraction, drawing toward them the hydrogen of the solar atmosphere. Moreover, the clearly defined whirls point to the existence of cyclonic storms or vortices.

The most striking of these storms occupies an enormous area in the southern hemisphere, extending from the equator to about 35°

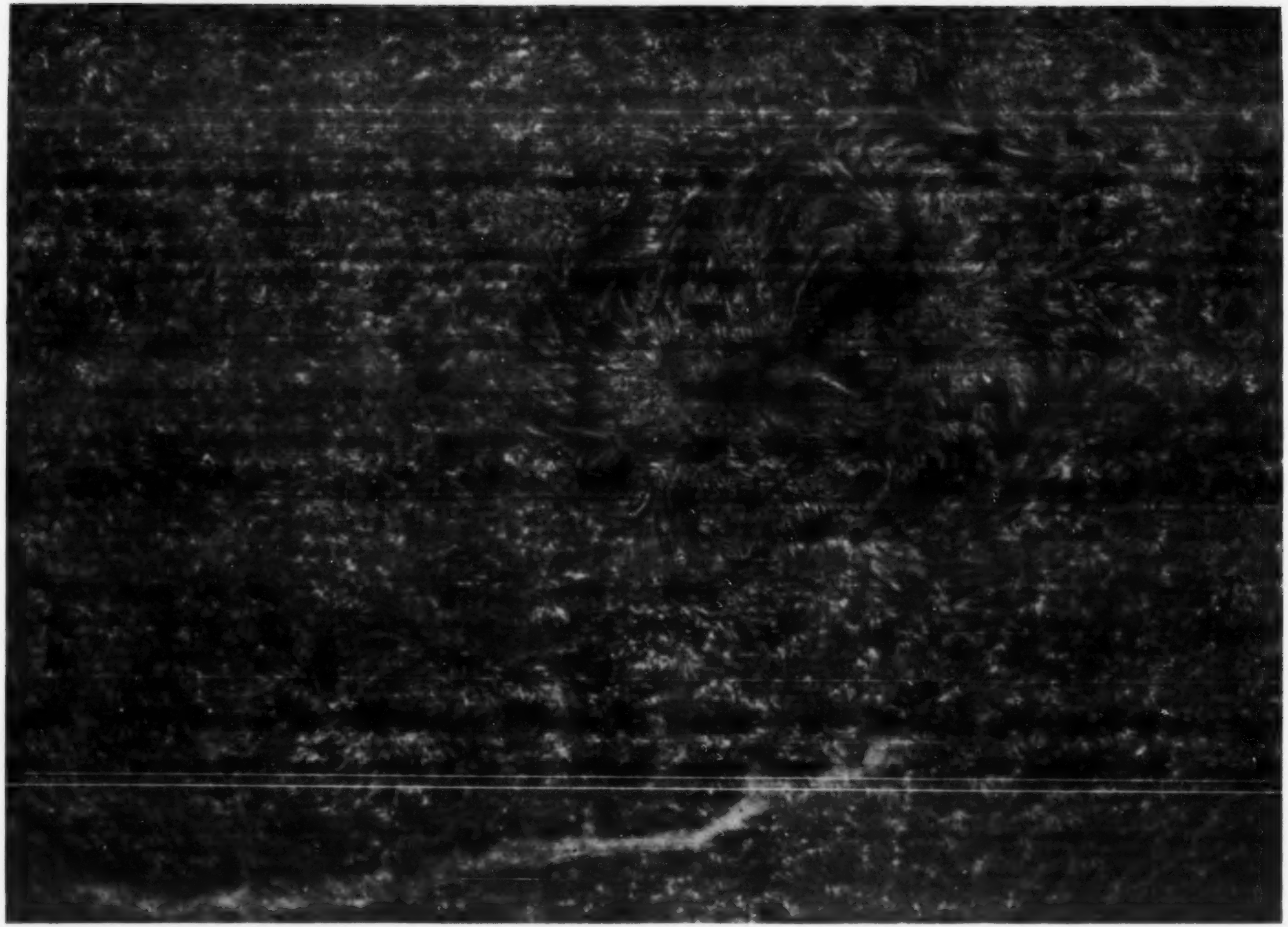
PLATE V



THE SUN, SHOWING THE HYDROGEN ($H\alpha$) FLOCCULI
1908, April 30, $5^h\ 06^m$ P. M.

PLATE VI

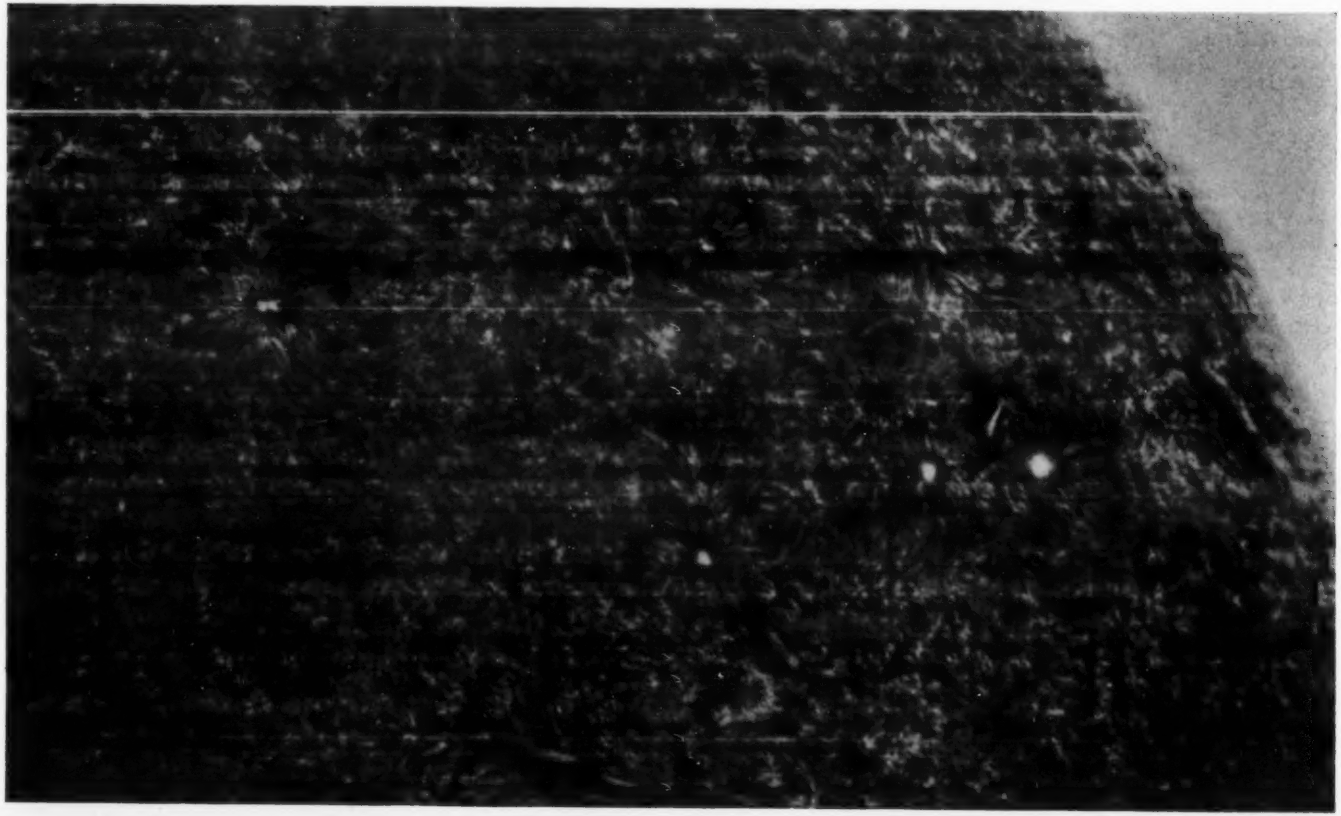
PLATE VI



HYDROGEN ($H\alpha$) FLOCCULI

1908, April 30, $5^h\ 06^m$ P. M. Large scale *negative* print showing portion of Plate V, reversed east and west. Scale: Sun's Diameter = 0.3 Meter

PLATE VII

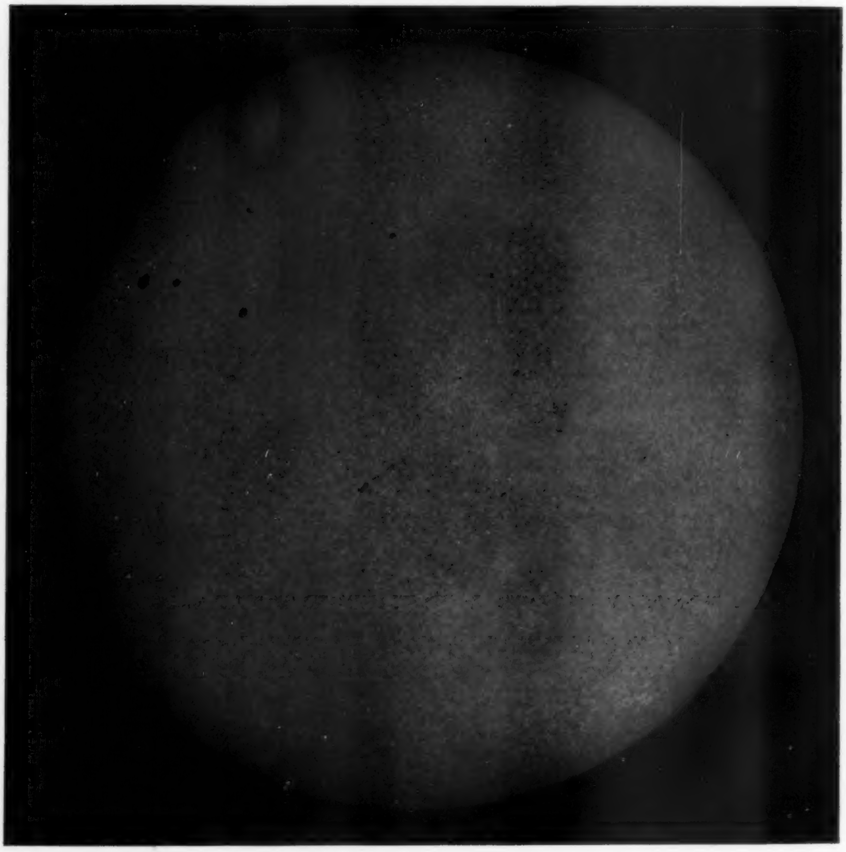


HYDROGEN ($H\alpha$) FLOCCULI SURROUNDING SUN-SPOTS

1908, April 30, $5^h\ 06^m$ P. M. Large scale *negative* print showing portion of Plate V, reversed east and west

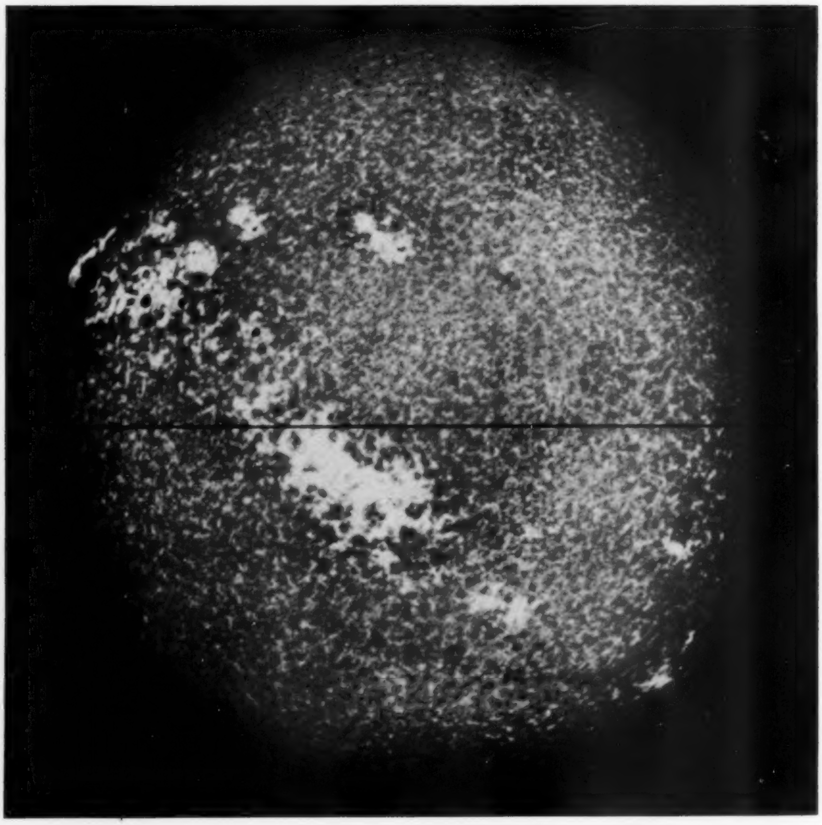
Scale: Sun's Diameter = 0.3 Meter

PLATE VIII



DIRECT PHOTOGRAPH OF THE SUN
1908, April 30, $6^h\ 25^m$ A. M.

PLATE IX



THE SUN, SHOWING THE CALCIUM (H_2) FLOCCULI
1908, April 30, $4^h\ 43^m$ P. M.

south latitude and about 50° in length. Near the center of this region, partly covered by clouds of bright hydrogen, lies the small spot-group shown (from a direct photograph) in Plate VIII. The corresponding H_2 photograph reveals a large calcium flocculus over the spot-group (Plate IX), but this, though of great size, appears to differ in no essential particular from ordinary calcium flocculi, and gives no evidence of gyratory motion.

A good $H\alpha$ photograph was obtained on April 29, but it was badly stained in the sensitizing process, and many of the flocculi are hidden by streaks on the negative. Fortunately, the greater part of the large storm area is fairly well shown, so that comparisons with the afternoon photograph of April 30 may be made in the stereo-comparator (using the monocular attachment). On account of the changes in form of the flocculi during this interval, the identification of objects suitable for measurement is very difficult and uncertain. Three independent determinations of the positions of certain flocculi on the two plates have been made by Miss Ware. The objects identified on both dates were marked by small dots of ink on the glass side of the negative, and their latitude and longitude measured with the heliomicrometer. When reduced to the same epoch (using for the value of the daily angular motion $\xi = 14\overset{\circ}{.}5$, derived from the measurement of 828 points on 35 $H\delta$ plates), the plotted results seem to show the existence of a gyratory motion, in a direction opposite to that of the hands of a watch (north, east, south, west). Although most of the points in a given region appear to move together, there are a sufficient number of apparently opposed motions to weaken seriously the value of the evidence. Unfortunately, an $H\delta$ plate taken on the morning of April 30 is not sharp enough to assist in the identifications. Further discussion of these plates is therefore postponed until additional data become available. On account of the complex character of such storms, a large number of photographs, taken at sufficiently short intervals to permit the flocculi to be identified with certainty, will be required to give satisfactory results. As our recent plates show that these storms are of common occurrence, and probably accompany every group containing several spots, there should be no difficulty in obtaining suitable photographs.

In the present paper I wish to illustrate the phenomena photo-

graphed with the aid of *Hα* in the neighborhood of a spot which reached the east limb of the sun at $8^h\ 16^m$ A. M. on May 26, 1908. A photograph of this spot, made by myself with *Hα* on May 29, at $4^h\ 26^m$ P. M. Pacific Standard Time, is reproduced in Fig. 1, Plate X. The whirl structure, which is clearly shown by this photograph, is also very distinct, though of somewhat different form, on the photograph of May 28. It is interesting to inquire as to the probable level of the region in which this whirl occurred, and the height of the long dark flocculus south of the spot. For this purpose we may examine photographs of the chromosphere and prominences at the limb, taken on May 25, 26, and 27. In the first of these, made on May 25 at $9^h\ 18^m$ A. M. (No. 4142), a long narrow prominence, extending toward the north, rises from the limb at position angle 92°, a point about one degree north of the spot. It makes an angle of about 12° with the limb, and fades out at the upper end, its length being approximately 90″ (geocentric). There are other small filamentary prominences in the region extending about 7° north of the spot, and smaller elevations in the chromosphere to the south. At P. A. 98° a bright prominence rises to a height of about 20″ and then slopes to the chromospheric level at P. A. 107°. Near its southern end is an independent filamentary prominence about 55″ high. On May 26, at $6^h\ 38^m$ A. M. (No. 4144), the prominences shown in Fig. 1, Plate IV, were photographed at the east limb. The lowest point in the chromosphere on this photograph corresponds to the position (P. A. 93°) where the spot crossed the limb about two hours later. It will be seen that these prominences, which extend from P. A. 82° to 106°, cover much of the region in which the whirl structure of Plate X appears. The prominence south of the spot is very bright and its highest point reaches an elevation of about 35″. On May 27, at $5^h\ 22^m$ P. M. (No. 4152), a prominence about 25″ high extends from position angle 105° to 109°. This is doubtless the eastern extremity of the strong flocculus in Plate X, which may be there seen curving toward the spot.

We may now pass in rapid survey the more important photographs of the disk. On May 28, at $6^h\ 58^m$ A. M. (No. 4157), the spot is near the east limb and the whirls are well shown. To the east of the spot is a long narrow line of bright hydrogen. On May 29, at

PLATE X

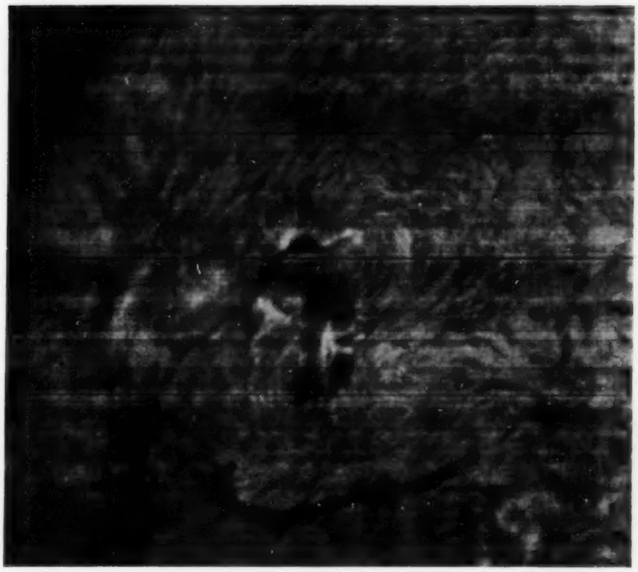


FIG. 1.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI
1908, May 29, 4^h 26^m P. M. Scale: Sun's Diameter = 0.3 Meter

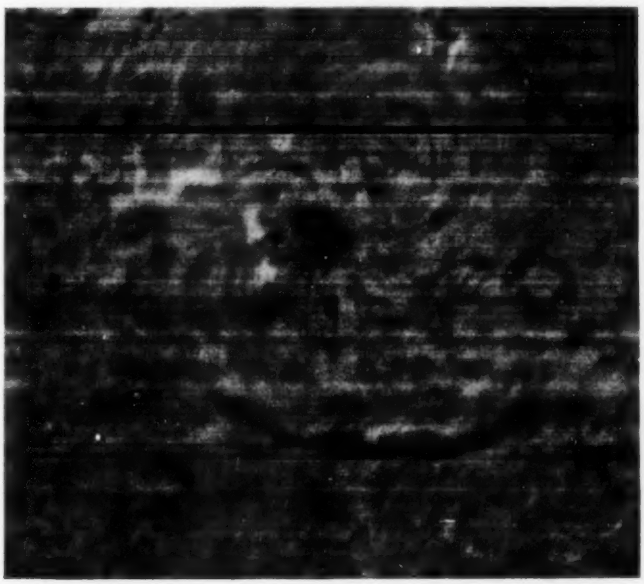


FIG. 2.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI
1908, June 2, 6^h 10^m A. M. Scale: Sun's Diameter = 0.3 Meter

$6^h\ 24^m$ A. M. (No. 4171), the whirls are very distinct and differ in many respects from those shown on May 28. Eruptive regions of bright hydrogen are seen southeast and west of the spot. The eastern end of the long dark flocculus is changing in form, and bridges are appearing over the spot. Negative No. 4175, taken $1^h\ 19^m$ later, seems to show distinct changes in the whirls, though they are not measurable. On May 29, at $4^h\ 26^m$ P. M. (No. 4176), the whirls resemble those shown in negative No. 4175, but exhibit some marked changes. An eruption which appears on the former plate southeast of the spot continues, but is changed in form and less brilliant than before. A strong eruption, of peculiar form, appears southwest of the spot, and bright hydrogen to the northeast. Strong dark flocculi have also developed at many points around the spot. The eastern end of the long dark flocculus is still changing, and a projection appears west of its center (see Plate X). A negative taken on the same day at $5^h\ 13^m$ P. M. (No. 4178) shows further changes in both bright and dark structure, especially in the region southwest of the spot. A fork has developed in the western end of the long dark flocculus, and a small but very dark flocculus appears just west of the spot. Another photograph (No. 4179), the first exposure of which was made at $5^h\ 26^m$ P. M., shows a bright eruption west of the spot, where the small dark flocculus appears on No. 4178. The eruption underwent considerable change of form while the five exposures on this plate, separated by intervals of a few minutes, were being made. At $6^h\ 04^m$ P. M. negative No. 4181 shows that the eruption had subsided and brings out other definite changes in structure near the spot. The small dark flocculus has disappeared. On May 31, at $8^h\ 09^m$ A. M. (No. 4188), the fork at the western extremity of the long dark flocculus has partially closed. No eruptions appear west of the spot, but there are bright ones to the southeast. Other important changes are evident, and the two bridges across the spot are conspicuous. On June 1, at $6^h\ 30^m$ A. M. (No. 4189), the fork at the western end of the long dark flocculus appears more nearly as it did in negative No. 4181, and the two bridges over the spot are very marked. A negative taken 15 minutes later (No. 4190) shows distinct changes, especially in the region south and southeast of the spot. At $5^h\ 08^m$ P. M. of the same day negative No. 4193 shows a

more distinct whirl near the spot, and the long dark flocculus appears to be growing shorter at its eastern end. On June 2, at $6^h\ 10^m$ A. M. (No. 4196), the whirling structure is very marked and more nearly symmetrical about the spot, which is divided into two parts (Fig. 2, Plate X). At $7^h\ 27^m$ A. M. (No. 4198) the whirl is also very marked and somewhat changed in form.

Up to this time the changes, while in many cases rapid, were not especially violent. On June 3, in an interval of about ten minutes, a remarkable transformation occurred. The long dark flocculus, which had been gradually changing in form and position, was suddenly drawn into the spot. As Fig. 2, Plate X, illustrates, the whirls were very conspicuous on the preceding day. A series of photographs, nine of which were made on negative No. 4201, between $4^h\ 48^m\ 09^s$ P. M. and $5^h\ 13^m\ 54^s$ P. M., and one, showing the entire disk, on negative No. 4202, at $5^h\ 22^m$ P. M., records the changes which took place during this time. These photographs were taken by Dr. C. E. St. John, who joined the Observatory staff in May, and is sharing with me the observational work with the five-foot spectroheliograph during Mr. Ellerman's absence on vacation. Three of these have been selected for reproduction. Fig. 1, Plate XI, is enlarged from a photograph made at $4^h\ 58^m\ 16^s$ P. M. (time of transit of spot across collimator slit of spectroheliograph). At $5^h\ 01^m\ 21^s$ the large dark flocculus is apparently unchanged in form. At $5^h\ 04^m\ 21^s$ an exposure, which is not quite so well defined, gives no certain evidence of change. The next exposure, made at $5^h\ 07^m\ 06^s$, clearly shows the development of a fork at the eastern end of the flocculus, with traces of a very faint curved extension toward the larger spot. The position of the end of the fork (C), as measured on this photograph, is given below, but the extension is too faint to be measured with certainty. The next exposure, made at $5^h\ 10^m\ 52^s$, shows the fork and part of the extension, but the definition is poor and the position of the end of the extension uncertain. The last exposure on this plate, made at $5^h\ 13^m\ 54^s$, is reproduced in Fig. 2, Plate XI. This admits of fairly satisfactory measurement, the results of which are given below. The spot region on negative No. 4202, made at $5^h\ 22^m$ P. M. (time of transit of spot), is reproduced in Fig. 1, Plate XII. Here the definition and contrast are

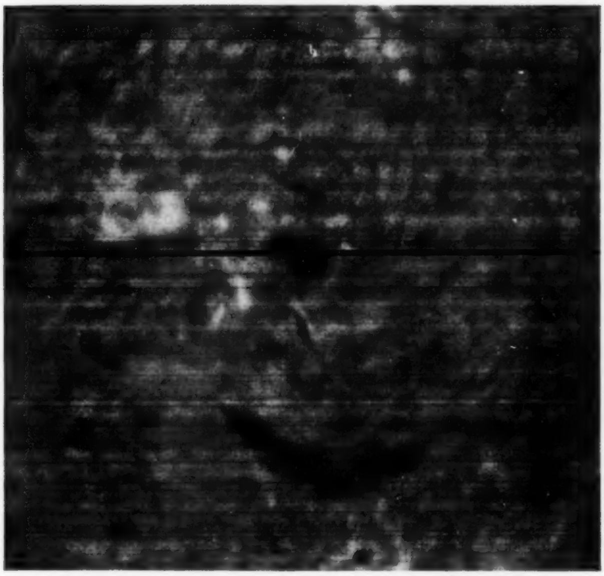


FIG. 1.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI
1908, June 3, $4^h\ 58^m\ 16^s$ P. M. Scale: Sun's Diameter = 0.3 Meter

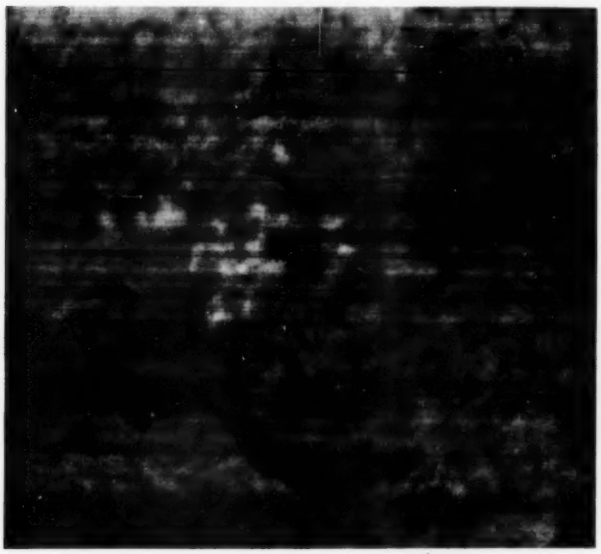


FIG. 2.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI
1908, June 3, $5^h\ 13^m\ 54^s$ P. M. Scale: Sun's Diameter = 0.3 Meter

PLATE XII

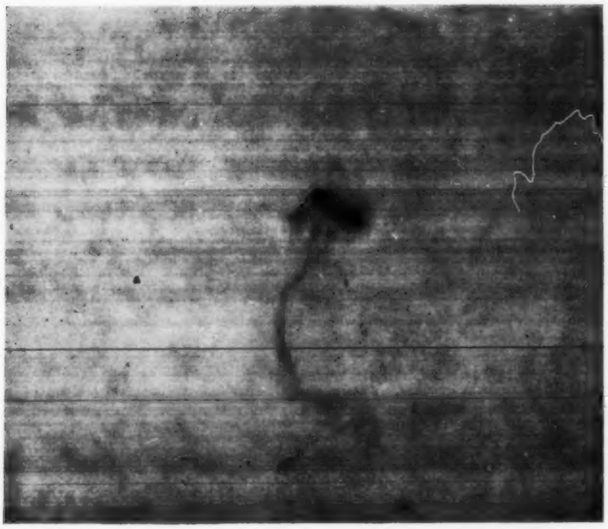


FIG. 1.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI
1908, June 3, $5^h\ 22^m$ P. M. Scale: Sun's Diameter = 0.3 Meter

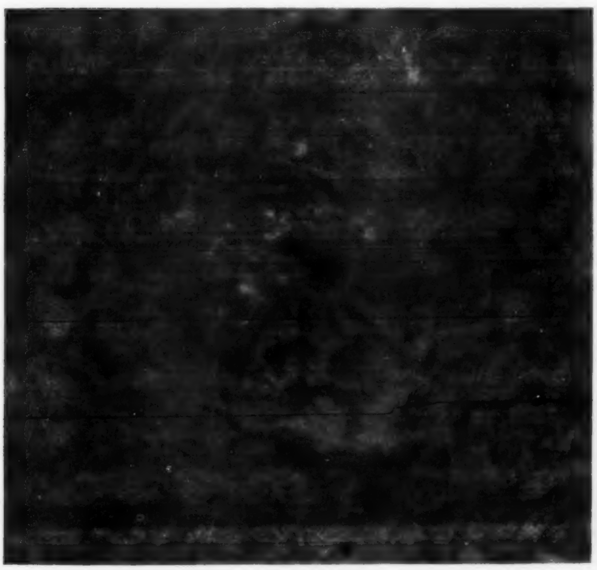


FIG. 2.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI
1908, June 4, $6^h\ 12^m$ A. M. Scale: Sun's Diameter = 0.3 Meter

also poor, but the extension, reaching nearly to the spots, is sufficiently well shown, as well as a dark flocculus which developed southeast of the smaller spot.

With the aid of the monocular attachment of the stereocomparator I have made a careful examination of all the photographs, and Miss Ware has measured the positions of the long dark flocculus with the heliomicrometer. If we call *A* the western extremity of this flocculus, *B* its eastern extremity, and *C* its point of nearest approach to the spot, we have the results of the measurements in Table I, which also include the positions of the two spots.

If we now take the measured differences in longitude and latitude of the large spot and the points *A*, *B*, and *C* respectively, and compute the corresponding distances, we have the results given in Table II.

These results show that the long dark flocculus gradually shortened, its eastern extremity apparently moving inward along the flocculus, while the distance of its western extremity from the spot did not change in a systematic manner. Accuracy of measurement is out of the question, as the flocculus varied so much in form from day to day that there can be no certainty in the identification of points that appear to correspond. A comparison of the series of photographs taken during the period of rapid development shows that the form and position of the main body of the flocculus did not greatly alter in this short interval, though the maximum of intensity moved rapidly toward the spots, leaving the body of the flocculus very faint. Even on these photographs, however, the velocity of the motion toward the spot cannot be precisely measured, partly because of the difficulty of determining where the extension ends and also because the time of the beginning of the phenomenon doubtless did not exactly coincide with the moment of exposure 6. Between exposures 6 and 7 we find for the point *C* a change of $1\overset{\circ}{.}9$ in latitude and $1\overset{\circ}{.}5$ in longitude. This corresponds to a motion of $2\overset{\circ}{.}4$ in 195 seconds, or 177 km per second. Between exposures 7 and 9, in an interval of 408 seconds, there was a change of $3\overset{\circ}{.}0$ in latitude and $0\overset{\circ}{.}4$ in longitude, giving a velocity of 89 km per second. Eight minutes later[1] the extension had divided and moved nearly to the spots, the resultant

[1] The time of negative No. 4202 is recorded only to the nearest minute.

motion for each extremity being 2°8, giving a velocity of 71 km per second.

TABLE I

Negative No.	Date	Point	Longitude	Latitude	Remarks
4176..........	May 29, 1908	A	32°0 E	5°8 S	B and B′ are the two
	4^h 26^m P. M.	B	48.6	13.6	extremities of east-
		B′	46.7	12.8	ern end of flocculus
		Spot	45.8	3.0	
		Spot	44.4	3.1	
4189..........	June 1, 1908	A	3.9 W	5.5 S	
	6^h 30^m A. M.	B	13.0 E	13.1	
		Spot	10.2	2.3	
		Spot	8.6	2.6	
4193..........	June 1, 1908	A	9.7 W	4.0 S	
	5^h 08^m P. M.	B	6.4 E	12.9	
		Spot	3.5	3.0	
		Spot	not measu	reable	
4196..........	June 2, 1908	A	16.9 W	5.5 S	A and A′ are the two
	6^h 10^m A. M.	A′	16.2	4.5	extremities of west-
		B	2.9	12.4	ern end of flocculus
		Spot	2.8	2.8	
		Spot	4.1	3.1	
4201, Exp. 5...	June 3, 1908	A	38.3 W	5.8 S	
	5^h 01^m 21^s P. M.	B	23.9	11.1	
		Spot	22.5	2.6	
		Spot	24.2	2.7	
4201, Exp. 6...	5^h 04^m 21^s P. M.	A	35.8 W	8.2 S	
		B	23.6	11.2	
		C	25.5	11.1	
		Spot	22.5	2.6	
		Spot	24.4	2.8	
4201, Exp. 7...	June 3, 1908	A	35.9 W	8.1 S	
	5^h 07^m 06^s P. M.	B	23.5	11.0	
		C	24.0	9.2	
		Spot	22.5	2.5	
		Spot	24.4	2.7	
4201, Exp. 9...	5^h 13^m 54^s P. M.	A	35.5 W	8.0 S	
		B	23.6	11.0	
		C	23.6	6.2	
		Spot	22.6	2.6	
		Spot	24.4	2.7	
4202..........	5^h 22^m P. M.	C	23.0 W	3.5 S	C approaches eastern spot
		C′	23.8	3.4	C′ approaches western spot
		Spot	24.5	2.6	
		Spot	22.7	2.5	

TABLE II

No. and Date	Longitude			Latitude			Distance		
	A-Spot	B-Spot	C-Spot	A-Spot	B-Spot	C-Spot	A-Spot	B-Spot	C-Spot
4176, May 29, $4^h\ 26^m$ P. M. . .	+12°4	−4°2		+2°7	+10°5		12°7	11°3	
4189, June 1, $6^h\ 30^m$ A. M. . . .	+12.5	−4.4		+2.9	+10.5		12.8	11.4	
4193, June 1, $5^h\ 08^m$ P. M. . . .	+13.2	−2.9		+1.0	+ 9.9		13.2	10.3	
4196, June 2, $6^h\ 10^m$ A. M. . . .	+12.8	−1.2		+2.4	+ 9.3		13.0	9.4	
	+12.1			+1.4			12.1		
4201, June 3									
Exp. 5, $5^h\ 01^m\ 21^s$ P. M. . . .	+14.1	−0.3		+3.1	+ 8.4		14.4	8.4	
Exp. 6, $5^h\ 04^m\ 21^s$ P. M. . . .	+11.4	−0.8	+1.1	+5.4	+ 8.4	+8.3	12.6	8.4	8.4
Exp. 7, $5^h\ 07^m\ 06^s$ P. M. . . .	+11.5	−0.9	−0.4	+5.4	+ 8.3	+6.5	12.7	8.3	6.5
Exp. 9, $5^h\ 13^m\ 54^s$ P. M. . . .	+11.1	−0.8	−0.8	+5.3	+ 8.3	+3.5	12.3	8.3	3.6
4202, June 3, $5^h\ 22^m$ P. M. . . .			C–E. Spot =0.3 C′–W. Spot =0.7			C–E. Spot =0.8 C′–W. Spot =1.0			C–E. Spot =1.0 C′–W. Spot =1.1

In order to check these measures, the stereocomparator was used to mark all of the points on a single plate, which was then measured differentially. The resulting velocities came out 140, 86, and 76 km per second respectively. Since the errors due to imperfect superposition in the stereocomparator should not differ markedly from those arising from a similar source in the heliomicrometer, the second set is given the same weight as the first. The differences among the three velocities cannot be trusted, though the evidence favors the view that the first velocity was actually higher than the others. The mean of the six measures (106 km) will at least serve to give the order of the maximum velocity in the vortex.

The appearance of the spot and surrounding region 13 hours after the rapid changes described above is shown in Fig. 2, Plate XII. The straight radial lines in this photograph are in marked contrast to the curved structure previously shown. The eastern of the more plainly marked radial lines is found by measurement to be a short distance to the east of the extension from the large flocculus to the spots shown in Fig. 2, Plate XI. The forked connection to the two spots has disappeared and a strong dark flocculus has developed at the southern extremity of the radial line, mainly on its eastern side. With the stereocomparator the main body of the large flocculus is found to resemble its former appearance in some particulars, but the distribution of intensities is very different and many changes in outline have occurred. In the photograph of June 5, $7^h\,05^m$ A. M. (No. 4220), the radial structure surrounding the spots is greatly altered and the flocculus, no longer recognizable, has developed a large extension toward the west (Fig. 1, Plate XIII[1]). A notable feature of this photograph is the amount of bright eruptive hydrogen in the region surrounding the two spots. Some eruptive matter also appears in the photographs of the preceding day, but here it is greatly augmented. A photograph taken on the same day, at $5^h\,19^m$ P. M. (No. 4227), is reproduced in Fig. 2, Plate XIII. It will be seen that the eruptions continue, and that the dark flocculi have undergone further important changes. The most notable of these is the connection which appears to be re-established between the two spots and the dark flocculus south of them. Apparently the dark hydrogen is

[1] There is a defect in this plate near the spots.

PLATE XIII

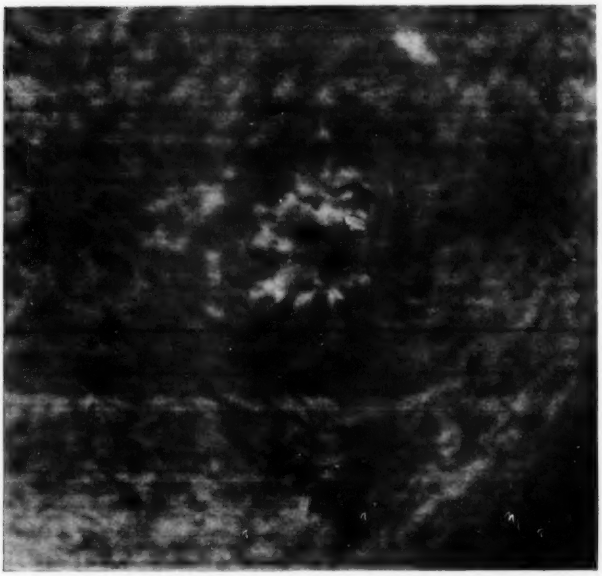


FIG. 1.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI
1908, June 5, $7^h\,05^m$ A. M. Scale: Sun's Diameter = 0.3 Meter

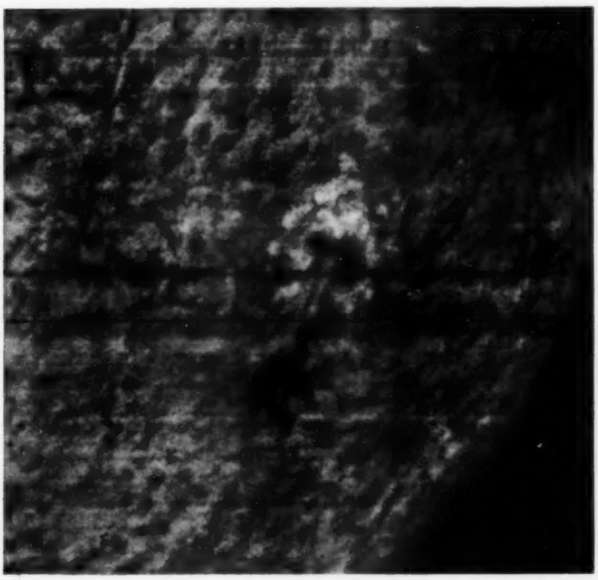


FIG. 2.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI
1908, June 5, $5^h\,19^m$ P. M. Scale: Sun's Diameter = 0.3 Meter

again being drawn into the spots. On June 7, at $7^h 56^m$ A. M. (No. 4244), a faint prominence appears on the limb south of the position of the spot. On June 8, at $7^h 42^m$ A. M., negative No. 4252 shows a group of prominences closely resembling in form those reproduced in Fig. 1, Plate IV, but very much less brilliant. On June 9 no prominence was photographed in this region.

As already remarked, the distance from the spot of the western extremity of the large flocculus did not vary systematically. The eastern extremity, on the contrary, commenced on June 1 to approach the spot, and continued to do so until the sudden change occurred on June 3. Up to this time the velocity, instead of showing signs of acceleration, was apparently retarded, but the changing form of the flocculus leaves this point uncertain. On the photograph of May 29 (No. 4176) the whirl is most conspicuous north of the spot, where its extreme distance is about equal to that of the western end of the large flocculus. Apparently, however, the flocculus did not fall completely under the influence of the vortex until June 1, when its eastern extremity was $11^\circ.4 = 140{,}000$ km from the spot. The fact that the minimum distance of the western end always exceeded this quantity may account for its escape.

In view of the nature of the phenomena described in this paper, and the fact that evidences of whirls or radial structure have been shown, in connection with several different spots, on a large number of *Hα* photographs, one is greatly tempted to enter at once into a discussion of the sun-spot theories of Faye, Reye, Emden, Halm, Bigelow, and Eckholm, all of which assume the existence of cyclones or vortices within the photosphere or the solar atmosphere. It is the part of prudence, however, to defer such discussion until our daily increasing supply of photographs is considerably enlarged. Moreover, I have devised improved methods for comparing photographs, which should facilitate the identification of objects for measurement, and experiments are also in progress with the purpose of bringing more clearly before the eye the nature of the changes which take place within the vortices. A simple kinetoscope has been advantageously used to observe the rapidly changing phenomena of June 3, and more elaborate apparatus of this kind will soon be available.

It may be well to direct attention, however, to certain points which have been noted:

1. In the series of photographs (on negatives Nos. 4201 and 4202) which show the large flocculus in the act of being drawn into the spots, the small flocculi near the spots remain almost unchanged in position, perhaps because of difference of level.

2. Except in the case of the large flocculus, attempts to detect evidences of motion toward the spots have not yet proved successful, even along apparent lines of flow.

3. Negative No. 4196, taken on June 2, shows a dark comet-like object (apparently defining a line of flow) intersecting a bright eruptive flocculus. The appearance suggests that the eruption does not rise to the level of the vortex.

4. Photographs of the $H\alpha$ line across bright flocculi, made in the second- and third-order spectra of the 30-foot tower spectrograph, indicate that this line has a complex structure which will require careful investigation.

5. Since the velocity of the hydrogen drawn into the vortex is of the same order as that of eruptive prominences, distortions of the hydrogen lines at the limb may be due to the motion of this gas in vortices. If the line of sight were to pass through a vortex, distortions toward violet and red observed at the same point might result from motions of approach and recession on opposite sides of the vortex.

6. The appearance of numerous hydrogen eruptions after the event of June 3 suggests that the hydrogen drawn down by the vortex subsequently rose to the surface in the neighborhood of the spots.

7. In view of the fact that the distribution of the hydrogen flocculi frequently resembles that of iron filings in a magnetic field, it is interesting to recall the exact correspondence between the analytical relations developed in the theory of vortices and in the theory of electro-magnetism.[1]

8. The gradual separation of the spots should not be overlooked.

Without entering at present into further details, a single suggestion relating to the possible existence of magnetic fields on the sun may perhaps be offered. We know from the investigations of

[1] See Lamb, *Hydrodynamics*, third edition, p. 201.

Rowland that the rapid revolution of electrically charged bodies will produce a magnetic field, in which the lines of force are at right angles to the plane of revolution. Corpuscles emitted by the photosphere may perhaps be drawn into the vortices,[1] or a preponderance of positive or negative ions may result from some other cause. When observed along the lines of force, many of the lines in the spot spectrum should be double, if they are produced in a strong magnetic field. Double lines, which look like reversals, have recently been photographed in spot spectra with the 30-foot spectrograph of the tower telescope,[2] confirming the visual observations of Young and Mitchell. It should be determined whether the components of these double lines are circularly polarized in opposite directions, or, if not, whether other less obvious indications of a magnetic field are present. I shall attempt the necessary observations as soon as a suitable spot appears on the sun.

MOUNT WILSON SOLAR OBSERVATORY
June 20, 1908

REMARKS ON THE PLATES

As it seems to be impossible to obtain illustrations which accurately represent the original negatives, certain remarks regarding the plates are required.

PLATE III.—Both figures are fairly satisfactory except that the limb of the sun, in the lower right-hand corner, is not properly shown.

PLATE IV, Fig. 1.—The position angles of various points in the prominences are given in the text of the article. The faint parallel lines, which make an acute angle with the sun's limb, are due to a slight irregularity in the motion of the spectroheliograph.

PLATE IV, Fig. 2.—The black dots are defects produced in the sensitizing process.

PLATE IV, Fig. 3.—The parallel lines are due to the cause mentioned above.

PLATE V.—This plate will serve to give a general idea of the appearance of the $H\alpha$ photograph of April 30, but fails to show the flocculi in their proper intensity. Although many bright flocculi appear to be present, especially in the upper part of the image, the original negative actually shows very few of these objects, the most conspicuous ones being in the midst of the great storm area in the southern hemisphere. For details see Plates VI and VII. The parallel vertical bands are due to a periodic motion of the spectroheliograph.

[1] J. J. Thomson, *Conduction of Electricity through Gases*, p. 164.

[2] Hale, *Contributions from the Mount Wilson Solar Observatory*, No. 23; *Astrophysical Journal*, **27**, 204, 1908.

PLATE VI.—As it was found by experiment that the flocculi on the photograph of April 30 are most accurately represented on a negative print, Plates VI and VII are reproduced in this way. Thus the light objects on both of these plates represent the dark *Hα* flocculi. The dark structure in the midst of the storm area in Plate VI is luminous hydrogen. The quality of this plate is more satisfactory than that of any other in the present collection.

PLATE VII.—This gives a fair idea of the flocculi in this region, though the limb is not well reproduced and certain regions near the spots and in the lower part of the plate are too black.

PLATE VIII.—The scale is so small that this illustration serves merely to indicate the distribution of the sun-spots on April 30, and the apparently insignificant nature of the group lying within the great storm area (near the center). The orientation is the same as for Plate V.

PLATE IX.—This gives a fair idea of the appearance of the calcium (H_2) flocculi, though the limb is not well reproduced. The orientation is the same as for Plate V.

PLATE X, Fig. 1.—The only bright flocculi that should appear in this figure are those in the neighborhood of the spot.

PLATE X, Fig. 2.—The background comes out too bright, giving the appearance of bright flocculi in regions where they are not present. The only objects of this class shown by the original negative are very conspicuous in the figure.

PLATE XI, Fig. 1.—This gives a fair idea of the original negative, the contrast of which is not very strong.

PLATE XI, Fig. 2.—The contrast of the original is much stronger than in the case of Fig. 1, hence the bright flocculi near the spot are relatively too conspicuous. The background in the upper part of the figure is also too bright.

PLATE XII, Fig. 1.—The original is lacking in contrast. The region to the left of the spot should be much darker than it appears in the cut.

PLATE XII, Fig. 2.—This is a fairly satisfactory reproduction, though the bright flocculi should be somewhat stronger.

PLATE XIII, Fig. 1.—Except for a defect in the photograph, the bright flocculi surrounding the spot are fairly well shown. In other parts of the figure, however, the background comes out too bright.

PLATE XIII, Fig. 2.—This is a fairly satisfactory reproduction, though the background is too bright in various places.

PRELIMINARY NOTE ON THE ROTATION OF THE SUN AS DETERMINED FROM THE MOTION OF DARK CALCIUM FLOCCULI

By PHILIP FOX

In the measurement with the globe machine of heliographic positions of the calcium flocculi shown on the Rumford spectroheliograms I have also included measurements of dark calcium flocculi wherever they were prominent features on the negatives. These dark flocculi are more easily recognizable when they are long and narrow. For such a flocculus it is my custom to measure the longitude east or west from the central meridian for each degree of latitude for all the parallels which the flocculus crosses.

Mr. C. Michie Smith has cited evidence that the dark calcium flocculi are prominences seen in projection on the disk. Observations by Evershed, by Buss, and by Hale and Ellerman are in accord. I have accumulated ample evidence from the Rumford spectroheliograms to confirm this. Plates obtained on November 7, 1907, give a good example of the coincidence in position angle of a dark flocculus at the limb and a prominence at 151°. Only a small percentage of the prominences shown at the limb, when carried upon the disk by the rotation, can be clearly followed there as dark calcium flocculi: I cannot say, as yet, what particular kind of prominence will be projected strongly dark on the disk.

Further indication that the dark calcium flocculi are high-level phenomena is shown by their coincidence with the dark hydrogen flocculi, pointed out by Hale and Ellerman.[1] Concerning this coincidence I may say that in general the dark hydrogen flocculi are more obvious than those of calcium, and I use the hydrogen plates when available, to facilitate the detection of the dark calcium flocculi. Stimulated by the success of Hale and Ellerman in obtaining negatives using the *Hα* line, I have begun such a series of plates which should be particularly serviceable in this regard. The dark hydrogen flocculi are very plain, and careful examination of the calcium

[1] *Publications of the Yerkes Observatory*, Vol. III, Part I, Plate VIII.

plates shows the coinciding flocculi to be present. The number of instances where prominences are traceable on the disk should in this way be greatly multiplied. A plate obtained today, June 15, 1908, gives a good instance at 107°. What success I have had with the *Ha* exposures I owe to Mr. Wallace, who prepared the "pan-iso" plates for the work.

TABLE I

Flocculus Number, Plate Number, and Date	Helio-graphic Latitude	Diurnal Motion, Sidereal	Diurnal Motion, Synodic	Longitude from Central Meridian		
				First Day	Second Day	Third Day
	−23	14°.42	13°.47	−25.0	−11.5	
	−24	14.02	13.07	−26.1	−12.3	
	−25	13.62	12.67	−26.4	−13.7	
Flocculus No. 1	−26	14.12	13.17	−27.4	−14.2	
Σ_s 1122, 1904, July 27, $8^h 15^m$	−27	13.02	13.07	−27.9	−14.8	
Σ_s 1130, 1904, July 28, $8^h 18^m$	−28	13.92	12.97	−28.1	−15.1	
	−29	13.52	12.57	−28.2	−15.6	
	−30	13.72	12.77	−28.5	−15.7	
	−31	13.92	12.97	−28.5	−15.5	
	−24	14.14	13.18	−32.5		− 6.3
	−25	14.04	13.08	−33.0	−20.5	− 7.0
	−26	14.14	13.18	−33.9	−20.9	− 7.7
Flocculus No. 2	−27	14.32	13.36	−34.8	−21.6	− 8.1
	−28	14.34	13.38	−35.4	−22.3	− 8.8
Σ_s 1207, 1904, Aug. 23, $8^h 59^m$	−29	14.55	13.59	−36.1	−23.0	− 9.1
Σ_s 1218, 1904, Aug. 24, $8^h 16^m$	−30	14.44	13.48	−37.0	−24.0	−10.2
Σ_s 1234, 1904, Aug. 25, $8^h 41^m$	−31	14.19	13.23	−37.2	−24.5	−10.9
	−32	14.04	13.08	−37.4	−25.0	−11.4
	−33	14.62	13.66		−26.0	−12.1
	−34	14.03	13.07		−26.5	−13.2
	−35	13.93	12.97		−27.3	−14.1
	+21	14.08	13.07	−11.5	1.6	
	22	13.98	12.97	−11.7	1.3	
	23	14.28	13.27	−11.8	1.5	
	24	14.28	13.27	−12.2	1.1	
Flocculus No. 3	25	14.38	13.37	−12.7	0.7	
Σ_s 1516, 1905, Feb. 17, $10^h 51^m$	26	13.88	12.87	−13.1	− 0.2	
Σ_s 1519, 1905, Feb. 18, $10^h 54^m$	27	14.68	13.67	−14.8	− 1.1	
	28	13.88	12.87	−15.2	− 2.3	
	29	14.08	13.07	−16.2	− 3.1	
	30	14.18	13.17	−17.2	− 4.0	
	31	14.08	13.07	−18.3	− 5.2	
	20	14.43	13.43	− 6.1	7.2	
Flocculus No. 4	21	14.63	13.63	− 7.0	6.5	
Σ_s 1543, 1905, Mar. 8, $11^h 19^m$	22	14.73	13.73	− 7.9	5.7	
Σ_s 1546, 1905, Mar. 9, $11^h 05^m$	23	14.43	13.43	− 8.9	4.4	
	24	14.73	13.73	− 9.8	3.8	

The evidence shows that the dark calcium flocculi are of the same order of height in the solar atmosphere as the hydrogen features and would therefore probably give results for the rotation of the sun in harmony with the hydrogen determinations. Two recent determinations of the solar rotation, the first by Hale,[1] giving values derived from the motions of hydrogen flocculi, the second by Adams,[2] from displacements of the hydrogen lines, show constant period for all latitudes, though the two methods yield a difference of nearly a degree in the diurnal motion.

I have collected in Table I my measurements of four dark flocculi. It should be pointed out that measurements of these high-level features should be confined to regions not too remote from the central meridian, for in projection they are displaced from the center of the disk and the resulting angular velocities would be too large. If the prominences were of considerable height this error would be very serious. I have discarded the observations of two dark flocculi because their longitude was greater than 40° from the central meridian. Two others were discarded because they extended nearly east and west, and the longitude for a given parallel was too uncertain.

I have collected the diurnal motions in Table II.

TABLE II

Heliographic Latitude	North			South			Mean Diurnal Motion	Group Mean
	3	4	Mean	1	2	Mean		
20°		14°43	14°43				14°43	
21	14°08	14.63	14.35				14.35	
22	13.98	14.73	14.36				14.35	
23	14.28	14.43	14.35	14°42		14°42	14.38	14°32
24	14.28	14.73	14.51	14.02	14°14	14.08	14.29	
25	14.38		14.38	13.62	14.04	13.83	14.10	
26	13.88		13.88	14.12	14.14	14.13	14.11	
27	14.68		14.68	13.02	14.32	13.67	14.17	
28	13.88		13.88	13.92	14.34	14.13	14.01	14°10
29	14.08		14.08	13.52	14.55	14.03	14.05	
30	14.18		14.18	13.72	14.44	14.08	14.13	
31	14.08		14.08	13.92	14.19	14.06	14.07	
32					14.04	14.04	14.04	
33					14.62	14.62	14.62	14°14
34					14.03	14.03	14.03	
35					13.93	13.93	13.93	

[1] *Astrophysical Journal*, **27**, 219, 1908. [2] *Ibid.*, **27**, 213, 1908.

The material is far too meager and the range of latitudes too small to warrant conclusions concerning polar retardation; but it is safe to say, after a comparison with the summarized results in Hale's paper,[1] that the motion agrees more closely with the motion of the hydrogen flocculi than with the hydrogen of the reversing layer, although the values are even closer to those of H_2 calcium.

YERKES OBSERVATORY
June 15, 1908

[1] *Loc. cit.*, Table III.

A STUDY OF THE ELECTRIC SPARK IN A MAGNETIC FIELD

By HELEN E. SCHAEFFER

A study of the deflection which magnetic and electrostatic fields produce upon the electric discharge at low pressures has given a clue to the nature of the particles concerned in the discharge, and has made possible measurements of their velocity and of the ratio of their charge to their mass. A similar study of the spark-discharge at atmospheric pressure has not been published, and it is the purpose of the present paper to present the results of such a study. The investigation has been undertaken with the idea that if a proper combination of conditions could be secured, a magnetic field might cause a deflection of such a character and magnitude as to separate the constituent parts of the spark, thus securing, as it were, a differentiation in space. Moreover, since the reflection from a mirror in rapid rotation indicates the time-changes which occur, the image thus obtained of the spark dispersed in a magnetic field would show the twofold separation of time and of space, and it was hoped that this separation might lead to a more detailed acquaintance with the mechanism of the electric spark.

Professor J. J. Thomson in his book, *The Conduction of Electricity through Gases*, makes on p. 522 the following statement:

> The effects produced by a magnetic field upon the spark at atmospheric pressure are very slight, although the halo of luminous gas which surrounds the course of the sparks when a number of sparks follow each other in rapid succession is drawn out into a broad band by the magnetic field.

He also states (on the same page) that Precht has found an effect of the magnetic field upon the spark at atmospheric pressure, if the spark terminals consist of a sharp point and a blunt wire; but Precht[1] has described the character of this deflection only so far as to say that its direction agrees with the electro-dynamic laws. Precht's paper is mainly concerned with a study of the different conditions in which one form of the discharge—spark, brush, or glow—becomes

[1] *Annalen der Physik*, **66**, 676, 1898.

changed into another, and of the changes in the potential difference of the terminals occurring under these different conditions.

The method of using a rapidly rotating mirror to show the separate oscillations which occur in the spark when a condenser is placed in the discharge circuit, was first employed by Feddersen,[1] who made use of it successfully to measure the period of the oscillatory discharge, and thus confirmed the theoretical work of William Thomson (Lord Kelvin). Following him many others have used it for similar measurements.

The use of a rotating mirror and later of a rotating film to gain an insight into the constitution of the electric spark was first made by Schuster and Hemsalech,[2] later by Schenck.[3] A glance at Plate XIV, Fig. 1, showing the appearance of the oscillatory spark when viewed in a rapidly rotating mirror, will make clear the summary of their combined results. The three general features of this discharge as given by Schenck are:

1. A brilliant white straight line due to the first discharge, which is sometimes followed by one or two similar weaker straight lines at intervals of half the complete period of the condenser.

2. Curved lines of light, which shoot out from the poles toward the center of the spark-gap with a velocity constantly diminishing as they move away from the poles. It will be noticed that, as the light advances from one pole, the light moving away from the opposite pole is either very weak or absent altogether.

3. A rather faint light, generally of a different color from the curved lines of light, which fills up the spark-gap and persists for a certain length of time, especially in the center of the spark-gap, after the oscillations die out.

Schuster and Hemsalech (*loc. cit.*) first found that sufficient self-induction in the discharge circuit causes the air lines to disappear from the spectrum of the spark. Later Hemsalech[4] discovered that when the self-induction is increased, the so-called spark lines disappear, whereas the arc lines in the spectrum of the spark become brighter. Schenck (*loc. cit.*) in turn made this difference the basis of a division of the lines of the spark spectrum into three groups, this division occupying the first part of his paper. These several experimental results as arrived at by Schuster, Hemsalech, and Schenck have all been noted during the present investigation, though their

[1] *Pogg. Ann.*, **116**, 132, 1862.

[2] *Phil. Trans.*, **193**, A, 189, 1900.

[3] *Astrophysical Journal*, **14**, 116, 1901.

[4] *Comptes Rendus*, **129**, 285, 1899.

bearing upon the problem here proposed is less immediate than that of other observations made by them.

The results which have a more intimate bearing here do not relate to the disappearance of the air, spark, and arc lines under certain conditions, but to what is true of them under all conditions. Since the photographs of the spectrum lines taken upon a rapidly rotating film showed the air lines to be entirely absent in all the spectra except that of the initial discharge, Schuster and Hemsalech concluded that only the initial discharge passed through the air.

By a similar method of studying the spectrum lines—the only variation being the use of a rotating mirror instead of a rotating film—Schenck brought out an interesting difference between the spark and arc lines, viz., that the spark lines appear sharply beaded to the end of the line, whereas the arc lines show only indistinct traces of beading, which do not extend to the end of the line. In other words, he concluded that the spark lines are due entirely to oscillations, while the arc lines are due partly to the oscillations and partly to something else which retains its luminosity after the oscillations cease. The spark lines are in the spectrum of the streamers which are described as the second feature of the spark; the arc lines in that of the vapor already mentioned as the third feature.

Furthermore, Schenck (*loc. cit.*) has found that the streamers emanate from the cathode and he has concluded that they do not carry the current. This view is supported by Hemsalech,[1] who, after identifying the streamers with the metallic vapor, advances the theory that the electric charge is not carried by the metallic vapor, but by the nitrogen. As addenda to his paper, Schenck gives the results of his investigation of the effect of a strong magnetic field upon the spark, the investigation having been concerned with the spark in a magnetic field of 10,000 units, both with and without the help of the rotating mirror, though his account as published includes only one feature of the change produced by the magnetic field. I quote from this account:

> With no magnetic field the spark lines and the arc lines extended clear across the gap. With the magnetic field the spark line of magnesium λ 4481 extended outward from each pole only about one-quarter of the way across the gap, leaving

[1] *Comptes Rendus*, **140**, 1103, 1905.

the center free from light of this wave-length, while the arc triplet at λ 5200 extended clear across as it did without the field. When examined with the mirror revolving, the line λ 4481 was broken up into a series of short streamers separated by intervals of darkness, while the arc triplet λ 5200 was in the form of a luminosity which advanced slowly (with a velocity not greater than 0.5×10^4 cm per second) toward the center of the spark-gap being crossed by a series of streamers. The noise of the spark was increased by the magnetic field.

It will be noticed that this description of the image given by the rotating mirror when the spark is in the magnetic field, is not essentially different from that given when the spark is out of the field. Other results relating to the disappearance of the spark lines under certain conditions, though in themselves of minor importance, are necessary to an understanding of conclusions applied by Walter[1] to the results of Schuster and Hemsalech, and involved in the discussion of the present paper. Walter has shown that if the self-induction in the discharge circuit having as spark terminals an alloy of zinc and copper, is increased, the disappearance of the spark lines of zinc before those of copper cannot be explained by the fact that the melting-point of zinc is lower that than of copper, an explanation suggested by Kowalski and Huber[2] in connection with their results. The basis of Walter's objection lies in the fact that under similar conditions he found the spark lines of lead to persist longer than those of copper; whereas, if the difference in the melting-points were the determining factor, the spark lines of lead should, like those of zinc, disappear before the spark lines of copper, since the melting-point of lead is also lower than that of copper. Accordingly Walter,[3] referring to a conclusion reached in one of his earlier investigations, viz., that the metallic vapor in the spark is formed at the negative pole, is led to decide that the metallic vapor must be a result of the disintegration of the cathode. He therefore thinks that the amount of disintegration which occurs at the cathode may be the important factor in determining which lines shall persist longest when the self-induction in the discharge circuit is increased, and he finds that the lines of that metal which suffers most disintegration at the cathode persist longest.

[1] *Annalen der Physik*, **21**, 223, 1906.

[2] *Comptes Rendus*, **142**, 994, 1906.

[3] *Boltzmann-Festschrift*, 647, 1904.

This conclusion, together with Schenck's observation that the spark lines are affected by the magnetic field, while the arc lines are not, Walter considers a sufficient explanation of the differences which Schenck and Hemsalech have observed in the behavior of the spark lines and arc lines. The metallic particles torn from the cathode by disintegration he thinks carry with them an electric charge which they do not lose until they have reached the center of the spark-gap. The spark lines are characteristic of the light from the metallic particles which carry an electric charge; the arc lines, of that from the metallic particles which have lost their charge.

To explain Hemsalech's result that increase of self-induction causes the spark lines to disappear from the spectrum and the arc lines to become brighter, he says that increase of self-induction lengthens the period of oscillation and decreases the current in the single oscillations. This decrease of current causes a longer interval to elapse between disintegration and luminescence of the particles, thus giving time for a greater number of particles to lose their charge. With added self-induction the ratio of the uncharged particles to those charged increases. Therefore the arc lines characteristic of the uncharged particles are brighter than the spark lines characteristic of the charged particles.

Returning to the results of Schuster and Hemsalech, we find that by means of the curvature which a rotation of the photographic film produces in the metallic spectrum lines, they have obtained as the magnitude of the velocity of the particles of many different metals a value of 4×10^4 cm per second. Schenck, on the other hand, obtaining a value of 25×10^4 cm per second, is led to believe that the difference between his values and those of Schuster and Hemsalech may be due to the fact that they measured the slope of the locus of the extremities of the streamers, while he measured the slope of the streamer itself.

The present investigation may be divided into three parts:

I. A study of the visible space-changes which the presence of a strong magnetic field causes in the spark.

II. A spectroscopic analysis of the different parts into which the spark is spread out under the influence of the magnetic field, this analysis being made solely for purposes of identification.

III. A study of the image of the spark given by a rapidly rotating mirror when the spark is in a magnetic field. The object of this part of the experiment was to get a second differentiation of the spark, viz., a differentiation with respect to time of the space-changes described in Part I.

Three types of electric spark were studied in each of the three parts of this investigation.

1. The spark obtained when neither capacity nor self-induction has been introduced into the secondary circuit of the induction coil.

2. The spark obtained when a capacity of 0.0005 to 0.012 microfarads has been introduced into the secondary circuit.

3. The spark obtained when a capacity of 0.0005 to 0.012 mf and a self-induction of 0.003 henries have been introduced into the secondary circuit.

APPARATUS

The spark was obtained from an induction coil, the primary of which was supplied by a direct current of one to four amperes taken from the 110-volt mains. The potential of the secondary could be raised high enough to produce a 32-cm spark between its poles. With a capacity of 0.012 mf and a self-induction of 0.003 henries in the secondary circuit, a spark of about 2 cm length passed between the metallic terminals. The capacity was obtained from Leyden jars arranged in parallel in the secondary circuit and was varied by gradually changing from a $\frac{1}{4}$-gal. jar to six 1-gal. jars, each 1-gal. jar giving a capacity of about 0.002 microfarads. The self-induction was obtained by placing in the secondary circuit four wire spools arranged in series. An adjustable resistance in the primary circuit served to change the spark from a very noisy to a hissing one. An approximately uniform magnetic field was obtained over a distance of about 2 cm by using truncated cones as the pole-pieces of a large DuBois electro-magnet.

The spectroscopic analysis was made by visual observations and photographs. The former were made by means of a calibrated prism-spectroscope which was mounted upon a carriage that could be moved at right angles to the rays of light falling upon the slit of the spectroscope. In this manner the spectra given by the different parts of the spark could be conveniently studied. The spectrograms

were made by means of a Fuess quartz-prism-spectrograph with camera attached.

For the third part of the investigation the image of the spark was reflected from a plane metallic mirror made by Brashear. This mirror was 5 cm in diameter and was mounted so that its rotation was about a horizontal axis. It was driven by a means of an electric motor and could be rotated at a speed of 200 revolutions per second, although a speed of about 50 revolutions per second usually sufficed. The speed of the mirror was measured by the impressions which a bristle attached to its axis made upon a revolving drum. These impressions showed that after the mirror had been in rotation for a short time its speed was practically constant and even such deviations from its constant value as occurred were found to be well within the limit of experimental error.

I. EFFECT OF THE MAGNETIC FIELD

The deflection produced by the magnetic field is most striking when the spark is allowed to pass along the lines of magnetic force or perpendicular to them, the deflection taking the form of circles in the latter case and of spirals in the former. (See Plate XIV, Figs. 3 and 2.) The spirals seem to be wound about cones of revolution, having different angles of divergence, whereas the circles all lie in a plane perpendicular to the lines of magnetic force. In a magnetic field of 1050 units the central threads do not participate in this spiral or circular form.

To appreciate in full detail this effect of the magnetic field upon the spark, a description of the three types of spark-discharge, as they appear both in and out of the field, will be necessary. The first type consists of one or two reddish-white threads which pass directly across the gap and are accompanied by a reddish, luminous vapor that assumes a yellow tinge when the current through the primary circuit is increased. Without the magnetic field this vapor forms an envelope about the central threads: in a parallel field it is deflected into a spiral sheet; in a transverse field into two semicircular sheets which are in the same plane. If the current through the primary circuit is sufficiently small, there is only one such spiral sheet in the first case, and only one plane semicircular sheet in the

second. If the current is increased, two spiral sheets or two semicircular ones are present and the latter two are in the same plane, one of them being on either side of the spark-gap. If, however, the spark terminals are drawn sufficiently far apart, one of the two spiral or semicircular sheets disappears entirely. In a field of 12,000 units, however—the strongest that could be obtained with the amount of current available, viz., 19 amperes—no deflection of the central threads could be noticed in either position of the magnetic field.

It was found that a small capacity in the discharge circuit introduced several reddish-white threads into the semicircular and spiral sheets. These threads took the form of spirals in a parallel field, the form of semicircles in a transverse field, and all lay in a single plane perpendicular to the lines of magnetic force. A slightly larger capacity in the discharge circuit made these threads more brilliant and increased their number. Strengthening the magnetic field also increased the number of these threads and their brilliancy. An increase in magnetic field-strength seems therefore to produce the same effect as an increase in capacity.

The second type of spark consisted of a bundle of very brilliant white threads, which were accompanied by little or no vapor. With a capacity greater than 0.002 mf this vapor was not present. In the magnetic field it assumed a circular or spiral form, according to the position of the spark-gap, and was accompanied by thin, brilliant white threads, which likewise were parts of circles or spirals. (Plate XIV, Fig. 5.) This vapor was yellowish in color, whatever terminals were used, and was spread out into a sheet that was so thin as to be almost invisible. The bundle of threads across the gap could not be changed by any available strength of field.

Plate XIV, Fig. 4, shows the central threads and metallic vapor of the third type of spark as they appear without the magnetic field. The threads are not so brilliant as those of the second type of spark, and have the same reddish color for all the metals tried as terminals. The color of this metallic vapor, however, varies with the metal used as spark terminal. With aluminium it is a bright green and shoots out from the electrode instead of enveloping it. With magnesium this vapor is yellow-green; with calcium, pink; with zinc, cadmium, and lead, orange-red with a blue core extending a short distance

from the electrode. This vapor does not appear to advance farther from the electrodes as the spark length is increased. It is therefore possible to separate the poles to such an extent that this vapor seems to be entirely absent from the center of the spark. With a given capacity in circuit the length of this vapor increases, however, with an increase of self-induction.

The figure just mentioned was taken from a photographic plate which was not sensitive to the reddish-yellow vapor enveloping the brilliant threads when no magnetic field is present. If the spark terminals are sufficiently far apart or the current through the primary is small this vapor is entirely absent. In the presence of the magnetic field it is changed to bright threads unless the spark terminals are close together. These threads are parts of circles or spirals according to the position of the spark terminals in the magnetic field. Strengthening the magnetic field increases their curvature. The color of these threads varies with the metals used as spark terminals. With aluminium they are reddish-white; with magnesium, red; with calcium, blue; with cadmium, reddish-purple; with zinc, lead, and bismuth, reddish-white. As the capacity and therefore the period is increased, these threads become broader, fewer in number, more red in color—where aluminium is concerned—and tend to depart from the plane perpendicular to the lines of magnetic force in a transverse field. Changing the amount of self-induction in the circuit does not seem to introduce any change into the form or number of the threads; but, if with a capacity of 0.002 mf in a circuit the self-induction is entirely removed, the threads are brilliant white instead of being reddish in color, and they disappear from the immediate region of the central threads, thus decreasing their number considerably. (Compare, Plate XIV, Figs. 7 and 5.) When self-induction is present, these threads which take the form of circles or spirals, according to the position of the spark-gap, can be obtained with a capacity as great as 0.012 mf. Without self-induction it is impossible to obtain any spiral or circular threads with a capacity greater than 0.002 mf. The number of these threads present when the third type of spark is in a magnetic field, passes through a maximum as the capacity is increased from 0.0005 to 0.012 mf, this maximum number occurring when the capacity is about 0.002 mf.

The number of threads present in the second type of spark also passes through a maximum, but here the maximum number occurs when the capacity has a much smaller value, comparable with that obtained from a small parallel-plate condenser. On the other hand, the width of the threads in both types of spark does not pass through a maximum for the range of capacities used, but steadily increases as the capacity is increased. If the electrodes are so far apart that without the magnetic field no vapor envelops the central threads, none of these circular or spiral threads is present when the magnetic field is on. It the electrodes are close together, the vapor is spread by the field into a yellow, circular or spiral sheet, instead of being broken up into brilliant circular or spiral threads.

It requires a much stronger field, however (about 12,000 as compared with 1050), to secure a noticeable change in the central threads. They are twisted by a very strong field along the spark length into a spiral, much like the thread of a screw, and of small radius. (See Plate XIV, Fig. 6.) A field at right angles to the spark length seems to cause a very slight general curvature in these central threads and also to make them appear crenate, the whole being concave to the spark-gap. The number of spiral turns or small semicircles does not in the latter case remain constant, and this irregularity suggests that these spirals or semicircles may be brought about by a sudden change in the velocity of the particles resulting from a loss or gain of electrons.

With this field of 12,000, the metallic vapor of the third type of spark also undergoes a deflection. In a transverse field it certainly assumes a circular form, but in one that is parallel, its form though much changed is too indistinct to be called that of a spiral.

The results thus obtained when any of the three types of spark is in a magnetic field are interesting if compared with the results obtained by Wehnelt,[1] when a hot lime cathode was used for the discharge at low pressures. He found that the particles emitted by a hot lime cathode bring to luminescence the gas through which they pass, and this luminescence indicates the spiral, or circular paths in which charged particles under the influence of a parallel or transverse magnetic field have been shown theoretically to move.

[1] *Annalen der Physik*, 14, 425, 1904.

The present investigation seems to show that also at atmospheric pressure there are particles which describe luminous paths in the form of spirals and circles. A much stronger field is necessary to produce the deflection here than at low pressures and the radii of the spirals and circles are much smaller.

These observations seem to justify two conclusions, at least, as regards those particles with which luminescence in the spark at atmospheric pressure is associated:

1. They obey in general the laws of motion which experiment and theory have shown charged particles to obey when at low pressure and under the influence of a magnetic field.

2. The obedience to these laws certainly lends strong support to the view that the particles carry an electric charge.

For two reasons it has at present seemed impracticable to find out whether the curvature of the path of these particles, as given by actual measurement, satisfies an equation deduced from theoretical considerations. The electrical conditions are seriously complicated by the necessity of having the electrodes sufficiently close for the passage of a spark at atmospheric pressure, and it would therefore be difficult to find the true values and directions of the electrical forces. The mathematical theory of the behavior of charged particles in a magnetic field has been worked out only in a general way for atmospheric pressure.

Figs. 7 and 8 show a twofold asymmetry in the deflection produced by a magnetic field: (1) an asymmetry at the electrode itself; (2) an asymmetry in the width of the two semicircular, luminous sheets. The latter asymmetry will be considered first.

Figs. 7, 8, 10, and 11 show the difference in the width of the two semicircular sheets. This difference also seemed to exist in the two spiral sheets, but their position as well as their spiral form made it more difficult to compare their respective widths. When the direction of the current through the primary, or that of the magnetic field is reversed these two sheets exchange places (compare Figs. 11 and 10 with Fig. 8). Furthermore when the current through the primary is decreased, or the distance between the spark terminals is increased, both of the sheets become steadily narrower, until finally a stage is reached where only one of the two is present.

The difference in the width of the two sheets can hardly be explained by the fact that the magnetic field may not have been entirely uniform throughout the region of the spark, since this difference in width was found to persist even in that part of the field which was far from uniform. An explanation might be sought in the fact that on one side of the spark-gap the magnetic field, due to the passage of the current, reinforces the permanent field given by the electro-magnet, while on the other side of the spark-gap, it weakens the permanent field. This explanation, however, would require both sheets to be produced at the same time and this simultaneous passage seems improbable since both sheets are later found to be due to particles of like charge. Fig. 9 seems to indicate that the two sheets are not formed at the same time. This photograph was taken when both sheets appeared to be present; yet it shows only one sheet of threads, thus suggesting that the exposure ($\frac{1}{60}$ sec.) was short enough for the set of threads on one side of the spark-gap to be photographed before that on the other was formed.

At the spark terminals the ends of the sheet are asymmetric in the following respect. One end of the semicircular boundary rests on the point of the electrode, while the other end of the boundary is at some distance from the point of the opposite electrode, as may be seen in Figs. 8, 10, and 11.

It has already been stated that the image given by the rotating mirror shows the particles with which these luminous sheets are connected to be most probably negative. If they are negative, then the direction of the field, together with the direction of the deflection, shows that they *advance* from the point of the electrode and *end* in a straight line extending for some distance along the other electrode.

In terms of the brilliant circular threads, characteristic of the spark which results when both capacity and self-induction are inserted into the secondary circuit, this asymmetric form at the electrode may be described thus: The threads all proceed from the extreme end of the negative electrode and end at different points on the positive electrode, these different points being in a straight line and all lying in the plane of the sheet which is perpendicular to the lines of magnetic force. (See Plate XIV, Fig. 7.)

Actual measurement has shown that these circular threads do not

possess the same radius of curvature. The asymmetry at the spark terminal may, accordingly, have no deeper significance than the fact that the circular threads are compelled to end upon different points of the positive terminal because their curvature is different, whereas they all start from the same point of the opposite, negative terminal because its potential is higher than that of any other part.

It has already been noticed, too, that if the conical end of the metal terminal is not perfectly smooth, the sheet sometimes starts from one or two other points in addition to the extreme point of the spark terminal. These few points were very different, however, from the line of points in which the sheet ended on the opposite spark terminal—that line of points lying, together with the axis of the spark terminal, in a plane which was at right angles to the magnetic field. Except at the few points from which the sheet seemed to proceed, a space could be seen between the sheet and the terminal from which the particles appeared to start. At the opposite, positive terminal no such separation could be seen between any part of the sheet and the spark terminal. When, therefore, the sheets seemed to start also from other points of the negative terminal, it was supposed due to the fact that an unevenness of the surface of the terminal caused these points to act as additional centers of discharge.

Fig. 10 shows the change which occurs in the position of the sheets when the direction used above for the magnetic field is reversed. It will be seen that the two sheets interchange sides as though each were turned through an angle of 180° about an axis along the spark length.

Fig. 11 shows another difference in the position of sheets, occurring when the current through the primary is reversed, the sheets here undergoing what might be termed a diagonal inversion. Not only does each sheet turn through an angle of 180° about an axis along the spark length, but each end turns, as it were, through another angle of 180° about an axis perpendicular to the spark length and in the plane of the sheet.

The first type of inversion is in entire agreement with such a change in the deflection, as a moving charged particle would experience in a magnetic field in which the direction has been reversed. The second type is also what the electro-dynamic laws would lead

one to expect for reversal of current through the primary of the induction coil.

II. A SPECTROSCOPIC ANALYSIS OF THE DIFFERENT PARTS OF THE SPARK

An image of the semicircular, reddish sheet presented in a transverse magnetic field by the first type of spark was focused upon the slit of a quartz spectroscope. The slit was at right angles to the spark length so that if any differences existed in the various parts of the sheet they might be shown upon the same plate. A magnetic field sufficiently weak to keep out of the sheet all reddish, circular threads was chosen.

Three different spectrograms were made of each of the following metals: aluminium, bismuth, zinc, cadmium, and lead. The first shows the spectrum of the outer part of the semicircular sheet; the second, that of the part containing the bright threads which pass straight across from pole to pole; the third, that of the third type of spark, taken merely as a means of comparison, and for this purpose it answers very well, inasmuch as the presence of self-induction brings into prominence the metallic lines. Plates were taken with the first spectrum directly above the third; others, with the second above the third. The first two spectrograms were given exposures of one hour; the third, of a minute.

As a result of these experiments the luminous sheet was found to present the same spectrum for each metal tried. This was the spectrum of the nitrogen bands and was found to correspond with that obtained from a low-pressure discharge tube containing nitrogen. The spectrum of the bright threads across the gap showed lines, identified visually with the so-called air lines, and lines corresponding in position to the metallic lines which show prominently in the third spectrogram. These three spectra may be seen in Figs. 12 and 13.

Since the sheets here studied show only the nitrogen bands in their spectrum, it seems probable that whereas their form indicates the path of the charged particles through the air, their luminescence is merely that of the air particles and is not in any way shared by a light characteristic of the metallic terminals from which the charged particles appear to come. On the other hand, since the central

threads have the metallic lines in their spectrum, there is reason to believe that they are, in some way, associated with particles which emit a radiation characteristic of the metallic terminals; but which cannot be considered as charged until a deflection or some other evidence is obtained.

The presence of the magnetic field introduces into the intensity of the lines a difference which is interesting. It will be remembered that, with the magnetic field absent, a yellowish vapor envelops the central threads, if sufficient current passes through the primary; also that with the field present, this vapor is spread out into a plane sheet passing through the spark-gap and perpendicular to the magnetic field, thus leaving the region about the central threads free from vapor except in the plane of this sheet. If the spark in the magnetic field is viewed side-on, i. e., if the spectroscope is placed so that no luminous vapor intervenes between it and the central threads, the metallic lines are brighter than when the field is absent. On the other hand, if the spectroscope is placed with its slit in the plane of the sheet of luminous vapor, so that the width of this sheet is between it and the central threads, the metallic lines are fainter than when the vapor surrounds the central threads, as always occurs when there is no field. Since an hour's exposure showed no evidence of these metallic lines in the spectrum of the vapor of the first type of spark, it seems probable that the decrease in the intensity of the metallic lines is due merely to the passage of the light through a cloud of particles and not to any such absorption as could cause a reversal.

The difference of intensity just described has also been noticed in the brightest metallic lines shown on the spectrograms of the third type of spark. When this type of spark is viewed side-on, these lines seem at least twice as bright in the field as out of it.

By extending to the second type of spark the spectroscopic analysis made for purposes of identification, it was found that the bundle of brilliant white threads which pass directly across from pole to pole and are undeflected by any available field have the well-known spectrum which presents itself when capacity is introduced into the secondary circuit, a spectrum consisting of bright air lines and fainter metallic lines. The spectrum lines of the circular threads

have the same wave-lengths as those of the non-deflectable threads, but they are much fainter. Throughout this paper the word *non-deflectable* is used in a purely relative sense, viz., that the central threads could not be deflected in any available strength of field of 12,000 units. Only for this type of spark is the spectrum of the circular threads the same as that of the threads which pass directly across the spark-gap.

In the third type of spark the investigation was concerned with the spectrum of the bright circular threads, that of the brilliant white central threads, and that of the vapor which extends several mm from the electrodes. All three different spectra were studied for electrodes of aluminium, zinc, bismuth, cadmium, lead, calcium, and magnesium, and no attempt was made to measure the lines with greater accuracy than was necessary for purposes of identification. For the visible spectrum a calibrated prism-spectroscope served to identify the arc, spark, and air lines accurately enough with those given for these metals in the charts of Hagenbach and Konen. The accompanying photographs show the spectrograms of the three different parts of the spark of each metal (taken directly, one above the other, upon the same plate). Plate XIV, Fig. 14, shows the spectrogram obtained when magnesium terminals were used. Fig. 15 shows the spectra of the central threads of each metal, taken one directly above another, and all by focusing upon the slit that part of the spark which is free from the metallic vapor. The time of exposure was two minutes for the spectra of the circular threads and of the central threads; one minute for those of the vapor close to the poles. For the spectra of the central threads the spark-gap was lengthened until the center appeared free from the metallic vapor enveloping the poles. The spectrograms obtained for the seven metals used as spark terminals, together with the visual observations upon the spectra of these metals, gave in general the following results:

1. The circular threads show spectra composed of faint air lines and the bright arc lines characteristic of the metal used. The spark lines appear to be entirely absent.

2. The central threads across the gap show the spectra of the air lines. Plate XIV, Fig. 15, shows that these spectra are practically the same for all the metals used. On some of them the metallic lines

show so faintly that the suggestion is rather that of a diffuse light reflected upon the slit than that of a light coming directly from the threads themselves. This view seems especially valid if one considers that with the spark terminals closer together the metallic lines of this type of spark are very much brighter than the air lines.

3. The vapor near the poles could not be isolated from either the central or the circular threads. Accordingly spectra taken in its region near the spark terminals showed very bright arc and spark lines together with very much fainter air lines. The other two spectra described above in 1 and 2 do not present the spark lines showing these spectra.

Varying the capacity or the self-induction changed only the intensities of the spectrum lines.

III. STUDY OF THE SPARK PLACED IN A MAGNETIC FIELD AND REFLECTED FROM A MIRROR IN RAPID ROTATION

To measure the velocity of the streamers, Schenck, and Schuster and Hemsalech used a method based upon a measurement of the slope of the streamer as given by the mirror in rapid rotation. As the luminescent vapor advanced from the spark terminal toward the center of the spark-gap, the light from this vapor reflected from the mirror when stationary and focused upon the photographic plate described a straight, horizontal line, a true representation of the path of the vapor. When the mirror is in rotation, however, this image is drawn out in a direction perpendicular to that in which the vapor is advancing. The resultant path on the plate is curved because the velocity of the vapor decreases as it approaches the center of the spark-gap.

This method, based upon a measurement of the apparent change of form introduced by the rotation of the mirror, would involve serious complications if it were used to measure the velocity of the particles from which arise the brilliant, circular threads of the spark of the third type. Measurement shows that the curvatures of the threads in a single spark vary considerably among themselves. Accordingly, even if two images of the same single spark-discharge were obtained—the one with the mirror in rapid rotation, the other with it at rest—it would be very difficult to match the threads in the

two images and then to measure the change of curvature introduced by the mirror. The existence of such a curvature change, however, suggests a simple method of measuring the velocity of the particles associated with the circular threads, and this method has been adopted in the present investigation. The method is this. The spark is made to pass in a horizontal plane parallel to the horizontal axis of the mirror. The spark terminals are so placed that with the mirror at rest the two ends of each circular thread are at exactly the same distance from the bottom of the photographic plate. When the mirror is set in rapid rotation, the image of each thread shows one end to be farther from the bottom of the plate than the other, this distance being greater for a long thread than for a short one. Evidently a time-interval must have elapsed between the formation of the two ends of the thread, and the existence of this time-interval shows that the luminosity of the circular threads must somehow be produced by the movement of a single set of particles from one pole toward the other, and not by two sets of particles which start simultaneously each from its own pole. From this time-interval may also be calculated the average velocity of particles. This average velocity is equal to the length of the circular path, divided by the time-interval above mentioned. This time-interval bears the same ratio to the time of one revolution of the mirror as that borne to 2π by the angle which is swept through in describing the distance a ($a = y_1 - y_2$, measured along the axis of y, Fig. 16) between the two ends of the thread. By means of a comparator, reading to thousandths of a millimeter, the distance a was measured upon a photographic plate which was moved parallel to the path described by the image of the spark across it. Readings to hundredths of a millimeter were found to be within the limit of experimental error. The length of the circular thread itself was measured by making a fine flexible wire coincide with an enlarged image of the thread, and then measuring the length of this wire after it had been straightened. Two errors are introduced into this latter measurement by the relative motions of the mirror and the particles. These two errors, being of opposite sign, offset each other. When the particle and the mirror are moving in the same direction, the length of the path of the moving particle is shorter in the image than it is in reality,

whereas, when they move in opposite directions, the path of the particle is longer in the image than in reality. As both these cases occur in the same semicircular thread the sum of the two errors becomes practically zero. Errors due to a displacement of the image by the rotation of the mirror were found to be well within the limit of experimental error. The spark terminals, besides being placed in such a position, were chosen of such a width and form that they could introduce no serious error into the measurement of a. The accompanying table gives the values of the velocities thus calculated from measurements upon the circular threads.

TABLE I

Number of 1-gallon Leyden Jars in Circuit	Values of the Velocity in cm per sec.
1	6.3×10^4 to 8.5×10^4
2	4.8×10^4 to 6.7×10^4
3	4.4×10^4 to 6.0×10^4
4	4.3×10^4 to 4.9×10^4
5	3.8×10^4 to 7.0×10^4
6	3.9×10^4

It is seen that the velocities are roughly of the order 5×10^4 cm per sec. Within the limit of error it cannot be said that there is any difference for threads of different curvature, nor is there a serious difference when the capacity is gradually changed from that given by one 1-gallon Leyden jar to that given by six 1-gallon Leyden jars.

This method may possibly be used to measure the velocity of the particles associated with the central threads, if the spark length be so adjusted that the threads remain in the same plane throughout their length.

This difference in the position of the two ends of a circular thread, as shown in the image reflected from the rotating mirror, also led to a determination of the sign of the charge carried by the particles whose velocity has just been calculated. According to the direction in which the mirror rotated, the end of the thread last formed was nearer or farther from the horizontal edge of the photographic plate. Thus from the direction of rotation and the position of the ends of the thread on the photographic plate, it was found which end of the thread was first formed, and this fact in turn indicated the pole from which the particle started and the direction in which it was moving. This direction, together with that of the deflection and that of the magnetic field, gave the sign of the charge carried by the particle. It was thus found that a negative charge is carried by the particles to which the easily deflected, circular threads are due.

As already stated, the equations of motion of a charged particle in a magnetic field are still, so far as atmospheric pressure is concerned, very general and incomplete. Moreover, the electrical conditions, complicated by the nearness of the electrodes required for the passage of a spark at atmospheric pressure, introduce other difficulties, so that it is not easy to arrive at an equation which will accurately represent the motion of these charged particles connected with the circular threads. The use of the equation $\frac{1}{\rho}=\frac{eH}{mv}$ in order to find the magnitude of $\frac{e}{m}$ would have no other justification than the fact that the path of these particles has approximately the same circular form as that of the particles in a low pressure discharge under similar magnetic conditions, the curvature of this form in the latter case satisfying the equation just mentioned. Some of the photographs show a change in the curvature of the threads at a distance of about 2 mm from the spark terminals. The radius of curvature then becomes smaller but has a constant value to within 2 mm of the opposite terminal, when it may become greater by as much as 5 per cent. In the present investigation

$$H=1050 \text{ c.g.s. units,}$$
$$V=5\times10^4 \text{ cm per sec.}$$

ρ varied from 0.4 cm to 0.7 cm, as may be seen in the accom-

panying table which gives the values of ρ for different amounts of capacity in the secondary circuit. If these values are substituted in the equation $\frac{1}{\rho}=\frac{eH}{mv}$, $\frac{e}{m}$ varies from 1.2×10^2 to 0.7×10^2.

TABLE II

Number of 1-gallon Leyden Jars in Circuit	I Series of Measurements Values of ρ in cm	II Series of Measurements Values of ρ in cm
1	0.56	$\begin{cases}0.42\\0.70\end{cases}$
2	0.60	$\begin{cases}0.52\\0.54\\0.60\\0.65\end{cases}$
3	0.55	$\begin{cases}0.50\\0.54\\0.60\end{cases}$
4	$\begin{cases}0.60\\0.55\\0.48\end{cases}$	0.43 0.45 $\begin{cases}0.57\\0.43\end{cases}$
5	0.45	0.45
6	0.40	$\begin{cases}0.40\\0.43\end{cases}$

Two or more values of ρ for the same number of Leyden jars are those belonging to different threads upon the same photograph, not several values of ρ belonging to the same thread. $\begin{cases}0.57\\0.43\end{cases}$ are the radii of curvature of different parts of the same thread, 0.57 being the ρ of the parts near the spark terminal.

Measurements were also made upon the slope of the streamers to find how the value obtained for these velocities agreed with the values obtained by Schenck, and Schuster and Hemsalech, Schenck having obtained a value of about 25×10^4 cm per sec.; Schuster and Hemsalech one of 4×10^4 cm per sec.

The measurements made here upon the streamers have shown a decrease in the velocity as the slope was measured from the electrode toward the center of the spark-gap, the values of the velocities ranging from 1×10^5 cm per sec. to 4×10^3 cm per sec. Measurements were taken only upon the part of the streamer which is not in the same direction as the path of the image across the plate.

Moreover, by closely examining the streamers it will be noticed that the second streamer advances farther toward the center of the spark-gap than the first, the third farther than the second, etc., the the brightness of each diminishing as it nears the center of the gap. The slope of each succeeding streamer becomes after a short time less abrupt than that of its predecessor and their points of junction finally lie on one continuous line, which is almost parallel to the path of the image across the photographic plate. It will also be noticed that the space between successive oscillations increases. This increase in space means that the interval of time between the oscillations becomes greater as they die out and this suggests that each streamer, before it joins the next one, approaches the center of the gap more nearly than its predecessors, for the reason that the vapor is there given a longer time to diffuse toward the center. The decrease in slope shows that the change in the velocity of the vapor becomes less abrupt with each successive oscillation, suggesting that the sum total of the forces which act upon the vapor changes less abruptly with each oscillation. This would naturally be expected from the curve of an oscillatory discharge. These observations, together with the results given on p. 141, lead one to think that Schenck may have been mistaken in suggesting —as he did, to explain the difference between his values for the velocity of the streamers and those of Schuster and Hemsalech— that they measured the slope of the *locus* of the extremities of the streamers. Such a locus is almost parallel to the path of the image of the spark across the photographic plate and a measurement of it could not possibly give for the velocity a value comparable with that secured by Schuster and Hemsalech. It seems possible therefore that the velocities measured were actually those of different parts of the streamer; Schenck having measured that of the part very near the electrode; Schuster, that of the part somewhat nearer the center of the spark-gap.

This possibility suggested that there might be for some of the metal terminals a noticeable difference in the parts of the streamer itself. With zinc, cadmium, and bismuth a difference in color was noticed. For a very short distance, not exceeding 2 mm, the streamer was of a brilliant blue color like that of the blue cone noticed in the vapor about the electrode. Then it changed to a dull blue and

afterward to an orange-red like that of the vapor at some distance from the electrode. Furthermore the color of the bright blue core is like that of the bright points of light seen where the sheet of vapor of the first type of spark just touches the metal terminals, and where the circular threads touch the terminals in the third type of spark, provided that a capacity less than 0.012 mf is present in the circuit.

Plate XIV, Fig. 17, shows the spectrum of the spark when the spark length is parallel to the slit of the spectroscope. The spark line λ 4481 of magnesium is seen to be present only in the region of the spark terminals, whereas the other lines extend entirely across the spark-gap. When other metals were used as terminals, similar plates, showing the spark lines present only in the neighborhood of the terminals, were obtained.

The photographs show that the vapor represented by the very bright part of the streamer exists for a short time in each oscillation, but does not persist until the next oscillation at that electrode has begun: it therefore does not receive a fresh addition from each successive oscillation. The rest of the vapor, on the other hand, does persist until after the second or still later oscillations have begun, and thus presents a continuous background of light, reinforced by each successive oscillation. Schenck, it will be remembered, found that the image of the spark line given by the rotating mirror was sharply beaded and that the parts of the line are separated by intervals of complete darkness. The arc lines, on the other hand, showed only indistinct traces of beading, such as would be given by a continuous background of light crossed by streamers. These two facts taken in connection with the foregoing description lead to the following inference. The bright core, entering with each oscillation and completely dying out before the next begins, has some association with the spark lines which show by their distinct beading that they arise from something ending before the next oscillation has begun. The rest of the vapor, on the other hand, bears some relation to the arc lines which, by their indistinct beading and continuous background, show that they are associated with something persisting throughout and receiving fresh additions with each successive oscillation.

By allowing the light from the spark to fall first upon a plane

grating, and then upon the rotating mirror an attempt was made to see if the spark lines extended only as far as the bright blue core and if they died out before the next oscillation. But for every metal tried, the spark lines in the visible spectrum were too close to the arc lines, and the image given by the mirror in rotation lasted too short a time to give any positive results in this connection.

This method of using a grating objectively and at the same time a mirror in rotation, did however show that the continuous spectrum is in the form of the irregular first discharge which extends across the spark-gap. (See Plate XIV, Fig. 1.) This figure also shows instead of one or two discharges as Schenck has observed (cf. p. 122) that there may be as many as six or seven discharges following the path of the first discharge.

The velocity of the streamers Schuster and Hemsalech found to be about 4×10^4 cm per sec. The order of the value obtained in the present investigation for the average velocity of the particles connected with the circular threads is 5×10^4 cm per sec.; and the close agreement between these two values led me to try to see if there were any relation between that part of the streamer measured by Schuster and Hemsalech, and the circular threads. It was thought that if an effect of the magnetic field upon the metallic vapor could be found, some relation between this vapor and the circular threads might be traced. Accordingly the oscillatory spark obtained with a capacity of 0.012 mf and a self-induction of 0.003 henries was made to pass in the strongest available magnetic field, in order to show whether the metallic vapor acts in a manner at all analogous to that characteristic of the brilliant circular threads occurring under conditions which are similar in every respect to the preceding except that less capacity is present in the discharge circuit. To obtain oscillations sufficiently separated for the study of the vapor just described a capacity of 0.012 mf was necessary, and this type of oscillatory spark showed no deflection in the magnetic field used for obtaining the circular threads. In a field of 12,000 units, however, the metallic vapor of this oscillatory spark was deflected into the form of broad, circular rings much like the circular threads, except that they were broad and not brilliant. It is possible that a much stronger field might introduce narrow, brilliant threads, just as an increase

in the strength of the field introduced threads into the sheet of vapor belonging to the first type of spark. The brilliant blue core still remained close to the spark terminal at the two ends of each broad ring of vapor. If the magnetic field had caused any change in the core, this change would be difficult to detect because of the shortness of the core.

Photographs both in and out of the magnetic field were then taken with the mirror in rotation, in order to show whether the magnetic field produced a difference in the streamers. Both the bright core and the other vapor of the streamers showed irregularities when the spark was in the magnetic field, and these irregularities were such as a curved deflection might introduce into the motion of the particles giving the streamers. This suggested that the bright core, as well as the rest of the metallic vapor, was associated with charged particles, and additional evidence for this theory was afforded by the circular form of this vapor in a very strong field. If then every luminous part of the spark is associated with charged particles, Walter's theory that the arc lines are due to particles which have lost their charge seems doubtful. In whatever part of the spark the arc lines may originate, it seems probable that they must in any case arise from a luminescence excited by charged particles, since every part of the oscillatory spark suffers some deflection in the magnetic field, and this deflection obeys the electro-dynamic laws.

These arguments taken alone are, of course, insufficient to prove that the bright core seen in the third type of spark and the bright points of light seen in the first type of spark at the terminals have as their characteristic spectrum lines the spark lines and that the vapor envelope has the arc lines; but they give a definite support to the theory. Such a theory if proved would add weight to Schenck's suggestion that the spark lines are due to peculiar vibrations arising when the atoms are torn from the metal terminals, whereas the arc lines are due to the more fundamental vibrations which persist after the abnormal vibrations have died out.

BRIEF SUMMARY OF RESULTS

The three types of spark studied are described on p. 126.

1. When the spark is placed in a magnetic field, the direction of

which is parallel to that of the spark-gap, the first type of spark presents two sheets of vapor in the form of spirals. In the field at right angles to the spark length this vapor is in the form of two semicircular sheets, one being on each side of the spark-gap in a plane perpendicular to the direction of the magnetic field.

In the second type of spark (if the capacity did not exceed 0.002 mf) and in the third type of spark brilliant spiral threads in a parallel field and brilliant circular threads in a transverse field took the place of the spiral and circular sheets respectively. In the first and second types of spark the bundle of threads across the gap could not be deflected by a magnetic field of 12,000, the strongest to be obtained with the available amount of current, viz., 19 amp. In the third type the metallic vapor and the threads across the gap were deflectable in a very strong field and in a manner analogous to that of the circular and spiral threads.

The character of the deflection seems to furnish good reason to infer that the particles with which luminosity is associated possess an electric charge. A twofold asymmetry is present in the deflection of the circular sheets of the first type and of the circular threads of the second and third types, viz., an asymmetry as to the terminals and as to the width of the two sheets or sets of threads. Reversing the direction of the magnetic field, or that of the current through the primary of the inductive coil, changes the position of the sheets and of their ends. Decreasing the current through the primary, or lengthening the spark-gap sufficiently, causes one sheet, or set of threads to disappear.

2. The circular sheet of the first type of spark gives the spectrum of the nitrogen bands. The central threads show that of the metallic lines and the air lines.

The second type gives the same spectrum for the bundle of central threads as for the circular threads, viz., that of the very bright air lines and the fainter metallic lines.

In the third type of spark the central threads show the same spectrum lines for each of the seven different metals which were used as spark terminals, these lines being identified with the air lines.

The spectrum of the circular threads shows the arc lines in addition to the air lines.

The spectrum of the part of the spark about the terminals shows the spark lines in addition to the arc and air lines. This gives the combined spectra of the metallic vapor, the circular and the central threads, because the metallic vapor could not be isolated.

These facts, together with certain observations presented at the end of this paper, give further evidence that the spark lines may be due to abnormal vibrations arising when the atoms are torn from the metal terminals; whereas the arc lines in the spark spectrum may be due to the more fundamental vibrations.

3. The value of the velocity of the particles associated with the circular threads is approximately 5×10^4 cm per sec. and this velocity is of the same order as that obtained for the streamers when they are measured close to the spark terminals.

These particles carry a negative charge.

They move in paths of different curvature.

Substituting in the equation

$$\rho=\frac{mv}{eH}$$

the values found for their velocity and for the curvature of their paths, $\frac{e}{m}$ is found to vary from 1.2×10^2 to 0.7×10^2.

The present investigation seems to show that in the electric discharge at atmospheric pressure there are negative particles which in a magnetic field describe luminous paths in the form of spirals and circles, similar to those described by the negative particles emitted by a hot lime cathode[1] in the discharge at low pressure.

The velocity of these particles in the discharge at atmospheric pressure is of the order of 5×10^4 cm per sec. whereas that of the particles in the discharge at low pressure is from 1.6×10^8 cm per sec. to 1.07×10^9 cm per sec.

It does not follow that these negative particles at atmospheric pressure are themselves luminous. The bright spiral and circular paths seen in a magnetic field may mean simply that the particles excite to luminescence the gas through which they pass. The nitrogen bands which constitute the spectrum of the spiral and circular sheets in the first type of spark seem to indicate either that the nega-

[1] Wehnelt, *loc. cit.*

tive particles associated with these sheets are capable of exciting a luminescence in the gas through which they pass, but have no luminescence of their own, or that the particles of air have themselves become ionized as well as excited to luminescence. The arc lines, however, which appear in addition to the air lines in the spectrum of the third type of spark, suggest that the charged particles here not only bring to luminescence the gas through which they pass but also that they themselves emit a radiation characteristic of the metal from which they appear to come.

The average velocity of the particles associated with these circular threads seems to be of the same order as that of the metallic vapor, as long as the latter is still close to the spark terminals. This agreement of the velocities and further the fact that the arc lines are present in the spectra of both the threads and the vapor, suggest some analogy between them.

Little that is definite can be said about the central threads. In the first and second types of spark they could not be deflected with a magnetic field up to 12,000, whereas in a field of this strength the central threads in the third type of spark assumed the form of spirals and semicircles, having a radius so small that measurements like those of the easily deflected threads were impossible. Thus far the spectra of these threads in the third type of spark give no clue to the nature of their mechanism.

The present investigation was suggested by Professor W. B. Huff, of Bryn Mawr College. I wish to acknowledge my indebtedness to him and to Dr. James Barnes, of Bryn Mawr College, for their helpful suggestions and criticisms during the course of the investigation.

PHYSICAL LABORATORY
BRYN MAWR COLLEGE
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DESCRIPTION OF PLATE

FIG. 1.—Oscillatory spark taken with the mirror in rotation. Speed of mirror —50 revolutions per sec., C=.012 mf., L=.003 henries. The lower figure shows the first discharge and six weaker discharges (*a*) which follow approximately the same path; also the short, curved streamers (*b*). The upper figure shows the trailing light (*c*). If the spark passes when the mirror is in exactly the right position, all these features may be seen in the same spark-discharge. P. 122.

FIG. 2.—Spirals. Spark-length parallel to the magnetic field. *Al* terminals. P. 127.

PLATE XIV

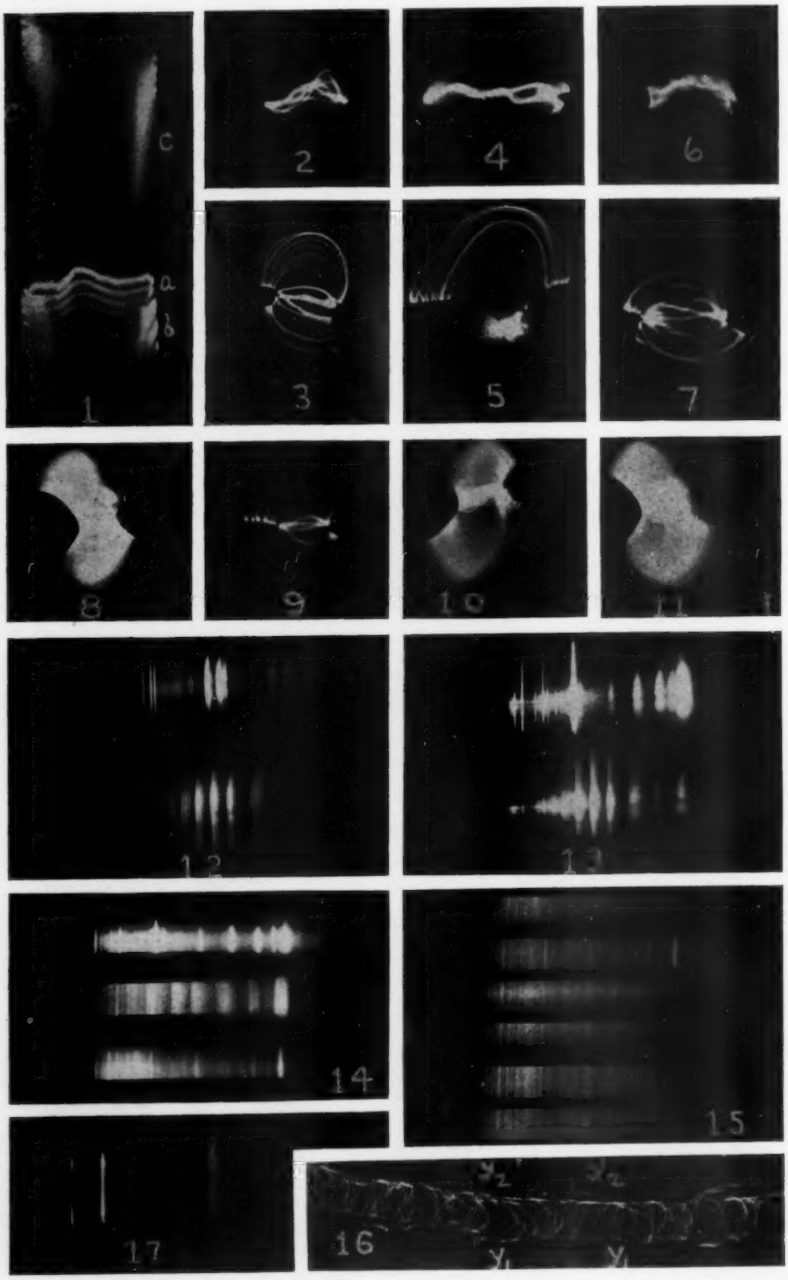


FIG. 3.—Circles. Spark length perpendicular to the magnetic field. The shape of the terminals did not permit complete semicircles below. P. 127.

FIG. 4.—Oscillatory spark with terminals too widely separated for the presence of the circular threads. It shows the vapor about the terminals and the irregular, central threads. P. 128.

FIG. 5.—Spark with a capacity of 0.0005 mf and no self-induction. It shows the bundle of bright threads straight across the spark-gap and the circular threads on one side of the gap. To the eye they were also present on the other side, but the short exposure of 1/50 sec. evidently "caught" the spark at an interval when they were present on one side only. Pp. 128 and 129.

FIG. 6.—Spiral form of the central threads in the oscillatory spark ($C=0.012$ mf, $L=0.003$ henries). The radius of curvature is too small for them to appear clearly in the photograph. P. 130.

FIG. 7.—To show the twofold asymmetry in the circular threads. Pp. 129, 131, and 132.

FIG. 8.—Asymmetry of sheets. Pp. 131 and 132.

FIG. 9.—Circular threads present only on one side of the spark-gap. P. 132.

FIG. 10.—Same, but direction of magnetic field reversed. Pp. 131, 132, and 133.

FIG. 11.—Same as 8 but direction of current through the primary reversed. This shows the bright points of light where the sheet meets the terminals. In figs. 8, 10, 11, on the left-hand side the sheets are partly hidden by the spark terminal. Pp. 131, 132, and 133.

FIG. 12.—Lower spectrum, that of the sheet in the first type of spark, taken with the outer edge of the sheet focused upon the slit. Upper spectrum that of spark, obtained with C, and L in the circuit, taken for purposes of comparison. *Cd* terminals. These spectra are not in focus on the right owing to the plane surface of the photographic plate. P. 134.

FIG. 13.—Lower spectrum that of the central threads and sheet of the first type of spark taken close to the terminal. Upper spectrum that of the spark, obtained with C and L in circuit, taken for purposes of comparison. *Mg* terminals. P. 134.

FIG. 14.—Spectra of three different parts of the oscillatory spark ($C=0.002$ mf, $L=0.003$ henries). Upper spectrum that of the metallic vapor, central threads, and circular threads, taken close to the spark terminal. Central spectrum that of the circular threads. Lower spectrum that of the central threads, taken in the center of the spark gap with terminals so far apart that center was free from metallic vapor. *Mg* terminals. P. 136.

FIG. 15.—Spectra of central threads of oscillatory spark taken in the following order from the top of the figure: *Al, Mg, Zn, Cd, Ca, Bi*. P. 136.

FIG. 16.—To show the images of the circular threads, secured with the mirror in rotation, upon which the measurements of the velocity of the particles associated with the circular threads were made. P. 138.

FIG. 17.—Spectrum of the spark ($L=0.0015$ henries) of magnesium taken with the spark length parallel to the slit of the spectroscope. P. 143.

ON THE ORBITAL ELEMENTS OF *ALGOL*

By R. H. CURTISS

It has long been known that the interval between successive light-minima of *Algol* varies minutely and irregularly. But as to the character of these inequalities little was recognized until 1888, when Chandler showed them to be closely represented by an empirical periodic expression involving three sine terms with periods of one hundred and thirty, thirty-five, and sixteen years. To account for the long-period term, which in its influence greatly transcends the others, Chandler postulated a third mass entering into a system about whose center of mass the eclipsing pair revolves in an orbit similar in size and form to that of *Uranus* in a period of 130 years. To account for the remaining inequalities he further suggested the presence in the system of a fourth body. In 1894 Bauschinger showed that Chandler's corroborative evidence based on variations in the proper motion was apparently illusory; and in the following year Tisserand proposed the alternative hypothesis that the long-period inequalities in *Algol's* minima are due to a revolution of the line of apsides of the slightly eccentric orbit of the eclipsing stars in a period of one hundred and thirty years, this revolution being attributable not to a third body but to a reasonable oblateness of the brighter star. Tisserand's value for the eccentricity (0.12), as well as the variations in duration of diminished brightness demanded by his hypothesis, are only approximately in accordance with the results of observation. There still remains a third possible hypothesis which postulates a third body relatively close to the eclipsing pair. In such a system perturbations arising from the mutual attraction of three bodies, of which one or more are probably oblate, could probably account for all irregularities observed in *Algol's* light-minima. It was to examine the evidence contained in recent radial velocity observations bearing upon these hypotheses, as well as to develop data for the guidance of spectroscopic observers in future work, that the following investigation was undertaken.

THE VELOCITY OF THE CENTER OF MASS OF THE ECLIPSING SYSTEM

The element whose variations bear most directly on the above hypotheses is the velocity of the eclipsing system. In 1906 Belopolsky assembled the five known values of this quantity and concluded that the observed variation of 15 km might not be real. At that time there had been published about 90 determinations of *Algol's* velocity taken in eight seasons, making an average of only eleven plates per season. Subsequently 157 measures of *Algol's* velocity in the seasons of 1905–6 and 1906–7 have been published by Belopolsky, Schlesinger, and the writer. From his own results Belopolsky concludes that "the above material does not as yet suffice for a determination of variations in the radial velocity of the system. Possibly that variation lies in the appearance of the spectrum lines; for example, in the unsymmetrical maxima found in them." But with the addition of independent evidence from 93 plates made at Allegheny Observatory and grouped about two epochs 0.3 years apart there seems good justification for an investigation of the data.

In Table I, I have assembled all the results of published data bearing on the center of mass velocity of the eclipsing system of *Algol*. In the first column appears the epoch of each set of plates formed by taking the mean of the dates of the plates involved. With

TABLE I

OBSERVED VELOCITIES OF THE CENTER OF MASS OF THE ECLIPSING STARS OF *Algol*

Epoch	Velocity	Systematic Reduction	Curvature Correction	Corrected Velocity	No. of Plates	Observers
	km	km	km	km		
1888.99	− 0.2	+5.2	±0.0	+ 5.0	3	Vogel and Scheiner
1889.94	± 0.0	+5.2	±0.0	+ 5.2	6	Vogel and Scheiner
1890.90	− 4.2	+5.2	±0.0	+ 1.0	3	Vogel and Scheiner
1897.80	− 2.0	±0.0	−0.1	− 2.1	24	Belopolsky
1898.73	+ 9.7	±0.0	±0.0	+ 9.7	8	Belopolsky
1902.94	+11.0	±0.0	+0.3	+11.3	20	Belopolsky
1903.90	− 4.0	±0.0	−0.2	− 4.2	15	Belopolsky
1905.01	+12.5	±0.0	+0.1	+12.6	14	Belopolsky
1906.06	+ 2.0	±0.0	±0.0	+ 2.0	23	Belopolsky
1906.82	+12.1	−0.9	+0.2	+11.4	44	Curtiss
1906.82	+ 7.5	+4.0	+0.2	+11.7	41	Schlesinger
1906.98	+ 6.5	±0.0	±0.0	+ 6.5	45	Belopolsky
1907.10	+ 3.9	−0.9	±0.0	+ 3.0	48	Curtiss
1907.11	− 1.7	+4.0	±0.0	+ 2.3	45	Schlesinger

the exception of the Allegheny observations each epoch corresponds to the plates for any one season. In the case excepted the observations naturally group themselves into two periods of two and three months each. Column 2 contains the values of the velocity of the system determined as described below. Columns 3 and 4 contain corrections necessary to reduce the velocity observations to homogeneity and are described below. Column 5 contains the final adopted values of the velocities. Column 6 gives the number of plates in each epoch and column 7, the observers' names.

PREPARATION OF OBSERVATIONS

Epochs 1888.99, 1889.94, and 1890.90.—For the determination of the center of mass velocity at these three epochs the final elements of Belopolsky based upon 117 observations of the years 1902–7 were accepted as standards. After eliminating the center of mass velocity the curve corresponding to these elements was accurately drawn on a large scale and the residual from that curve for each of the 1888–91 observations was graphically determined. The mean of the residuals for all the plates of each epoch was adopted as the velocity of the system for that epoch. In view of the suspected variation of some of the elements of the orbit of the eclipsing pair, errors may arise from this procedure which, since the observations do not suffice for independent determinations of eccentricity at these epochs, I have considered it best to adopt. Justification for this course seems to be ample in view of the character of the resulting residuals. But a further check is furnished by an independent value of +0.7 km for the center of mass velocity from the six observations of 1889–90 obtained by passing a smooth curve through them. Still further corroboration is afforded by Vogel's value of −3 km obtained from all twelve plates, agreeing with the mean of my three values within the limits of error. The treatment of the data is fully exemplified in the following Table II.

Epoch 1897.80.—The observations for this epoch were fully reduced by Belopolsky, whose value of the velocity of the system is here adopted.

Epoch 1898.73.—These eight observations of the fall of 1898 were not strong enough to determine a velocity-curve. They were

TABLE II

DETERMINATION OF RADIAL VELOCITIES OF CENTER OF MASS FOR EPOCHS 1888.99, 1889.94, AND 1890.90

Date	Phase	Velocity	Residual from Standard Curve
	year	km	km
1888, December 4	0.518	−38.9	±0.0
1889, January 6	1.937	+31.4	−4.7
1889, January 9	2.061	+43.9	+4.0
			Mean −0.2
1889, November 13	0.562	−38.9	+1.3
November 23	1.945	+38.2	+1.6
November 26	2.056	+38.0	−1.8
1889, December 21	1.147	−28.7	−3.4
1890, January 1	0.666	−40.4	+2.0
1890, January 3	2.656	+20.5	±0.0
			Mean ±0.0
1890, September 13	0.692	−43.8	−1.4
1890, October 13	1.976	+34.5	−3.7
1891, March 17	2.126	+35.6	−7.6
			Mean −4.2

reduced in the same manner as those of 1888–91. But the residual for each plate was determined not only from the 1902–7 elements of Belopolsky but also from the elements of 1897–8, with the velocity of the center of mass eliminated. The data are fully shown in Table III. In the final mean the results obtained from the two sets of elements were given equal weight. That the result obtained by using the elements of 1897–8 does better satisfy the final curve seems to be accidental in view of the character of the residuals in each case.

Epochs 1902–5.—For these three epochs I have adopted the mean of the two values published by Belopolsky in the *Mitteilungen der Nikolai-Hauptsternwarte zu Pulkowo*, Band **1**, No. 8, and Band **2**, No. 22. There is some probability that several plates of October, 1905, were included in the first reduction of the 1904–5 series, but as Belopolsky's two values for this epoch differ by one kilometer only, I have thought it safe to use the direct mean.

Epochs 1906.06 and 1906.98.—Belopolsky's published values were here adopted from the publications above cited.

TABLE III

REDUCTION OF 1898 OBSERVATIONS FOR DETERMINATION OF THE VELOCITY OF THE CENTER OF MASS

Date	Phase	Velocity	Residuals from Elements of 1902–7	Residuals from Elements of 1897.80
		km	km	km
1898, September 13........	0.997	−20	+15	+16
14........	1.969	+49	+11	+ 6
16........	1.068	−25	+ 6	+ 9
17........	2.089	+36	− 6	−12
19........	1.258	+10	+26	+34
25........	1.511	+11	+ 7	+17
October 3........	0.880	−17	+22	+21
4........	1.930	+29	− 7	−10
Means............			+9.3	+10.1

Epoch 1906.82.—In this case the observations of Dr. Schlesinger and he writer were treated separately. The velocity of center of mass of each observer expressed in the final elements was reduced to the epoch 1906.82 by applying an additive correction of 9.2 km in Dr. Schlesinger's case and 8.7 km in my own. These corrective terms were in each case the weighted mean of the residuals of the plates included in this epoch from the curve corresponding to the final elements.

Epoch 1907.10 and 1907.11.—In this case the velocity of center of mass of the final elements was reduced to the epoch of the plates by applying the corrections ±0.0 km for Schlesinger and −0.5 km for Curtiss, determined as in the above case by forming the weighted means of the residuals for each plate of this epoch from the curve of the final elements.

The systematic differences.—Column 3 of Table I contains the quantities necessary to reduce the observations made at Potsdam and Allegheny to homogeneity with those made at Pulkowa. In each instance the reduction to Belopolsky's zero was obtained from these observations themselves since such corrections were undoubtedly a function of the spectral type. For the Allegheny observations the systematic differences were evident at once, since the plates were contemporaneous with Belopolsky's series. For the Potsdam observations it was found, by applying the period obtained from the other measures, that these three early velocities formed a definite group

which could be reduced to the curve only by the application of a definite systematic correction. In seeking confirmation of this difference between Belopolsky's velocities for this stellar type and the early Potsdam results, I have employed the immediately available data contained in Scheiner's *Astronomical Spectroscopy* and Frost and Adams' paper on "Radial Velocities of Twenty Stars of the *Orion* Type." Since from the plates of *Algol* and from my own unpublished measures of β *Orionis* I am aware that the measures of Belopolsky, Frost, and myself are in close agreement, I have in the following Table IV compared directly the measures of Frost and Adams and of Vogel and Scheiner. A comparison for α *Andromedae* was taken directly from the *Publications of the Allegheny Observatory,* Vol. I, No. 3.

TABLE IV

Star	Frost and Adams' Velocity	Vogel and Scheiner's Velocity	Difference
	km	km	km
β *Orionis*	+20.7	+16.4	+4.3
γ *Orionis*	+18.0	+ 9.2	+8.8
ϵ *Orionis*	+26.5	+26.7	−0.2
ζ *Orionis*	+18.3	+14.8	+3.5
	Baker's Velocity		Mean +4.1
α *Andromedae*	+17	+5	+12
Algol	Belopolsky's Velocity − Vogel and Scheiner's		+5.2

In determining these systematic differences in the case of *Algol* I have not noted any certain effects due to the change of optical parts at Pulkowa and Allegheny during the observations.

Corrections for curvature.—In deriving the first values of the velocities of Table I it was in each case assumed that the value for the velocity of the system contained in the elements corresponded to the mean of all the dates. This assumption was justified when the observations extended along a nearly straight section of the curve, but near turning-points it was thought desirable to avoid the approximations involved in the above assumption by applying corrections depending upon the departure of the curve from a straight line. This small correction for curvature for any set of plates was derived with sufficient accuracy from one of the trial velocity-curves

of the center of mass by estimating on the graph the point representing the mean of the center of mass velocities corresponding to the plates in that set of observations assumed to be uniformly distributed on the section of the curve over which they extended. The residual of this point from the curve was adopted as a correction for curvature for this set of plates. The application of this correction increases the double amplitude of the final curve about 0.5 km but has no appreciable effect upon the period. The curvature corrections are given in column 4, Table I.

Determination of elements.—A preliminary study of the center of mass velocity observations since 1900 led to the assumption of the following circular elements: epoch of minimum velocity, 1902.3; period, 1.73 years; double amplitude, 19 km; velocity of three-body system, +4.3 km. These elements satisfied the later observations fairly well, but when it was attempted to extend them they were found to be inconsistent with the early Pulkowa and Potsdam measures. It was found, however, that the early Pulkowa measures could be brought approximately to the curve with periods of 1.54, 1.62, 1.90, and 2.07 years, and that the Potsdam observations could be adjusted roughly to the curve with periods of 1.62, 1.71, 1.81, 1.90, and 2.03 years. It was also evident that, of the values of the period which were roughly consistent with all the earlier measures, but two values, viz., 1.62 and 1.90 years, could also represent the later observations satisfactorily. Accordingly the first value of the period was studied and the following elements derived: epoch of minimum velocity, 1902.5; period, 1.624 years; double amplitude, 20 km; velocity of system, +6 km. As the residuals resulting from these elements were unwarrantably large the alternative value of 1.90 years was tried. From a study of all the observations on this basis during which some eight different sets of circular elements were tested, I have derived the following constants of the orbit of the center of mass of the eclipsing system of *Algol:*

E (epoch of minimum velocity)	1901.850 years
P (period)	1.899 years
$A=B$ (single amplitude of curve)	9.4 km
C (center of mass velocity)	+4.1 km
$R \sin i$ (the projected radius)	89,000,000 km
μ (mean yearly motion)	189°6

The velocity-curve corresponding to these elements together with all the observations of *Algol's* center of mass velocity are graphically represented in the accompanying diagram. Observations represented by single, double, and triple circles were determined from less than 20 plates, from 20 to 40 plates, and from over 40 plates, respectively. In the following table (V) is shown a comparison of the observed and computed velocities on the basis of the above elements. As a result of the numerous trials made with various sets of elements, I am inclined to think that the uncertainty in E, P, A, and C is not greater than 0.05 years, 0.01 years, 0.7 km, and 0.5 km respectively.

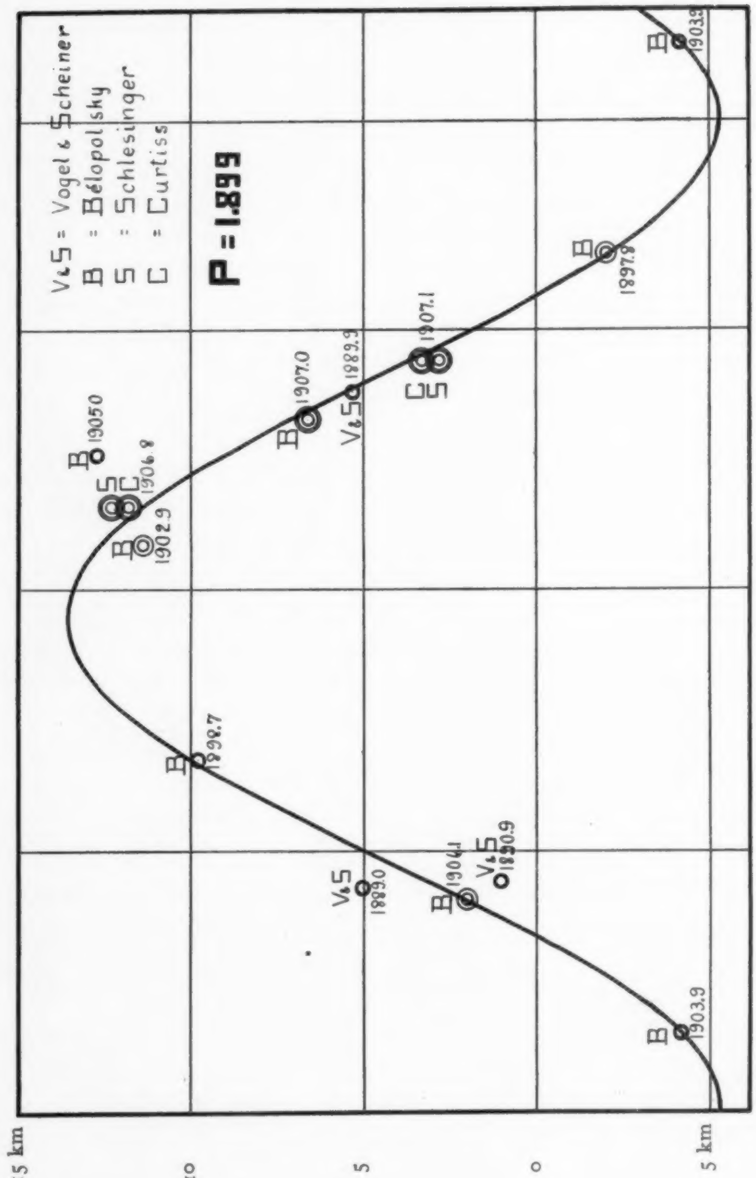
TABLE V

COMPARISON OF OBSERVED WITH COMPUTED VELOCITIES

Epoch in Years	Phase Referred to Minimum Velocity	Observed Velocity	Computed Velocity	Residuals	Number of Plates
	Years	km	km	km	
1903.90	0.15	− 4.2	− 4.2	±0.0	15
1906.06	0.41	+ 2.0	+ 2.1	−0.1	23
1888.99	0.43	+ 5.0	+ 2.7	+2.3	3
1890.90	0.44	+ 1.0	+ 3.0	−2.0	3
1898.73	0.68	+ 9.7	+10.0	−0.3	8
1902.94	1.09	+11.3	+12.5	−1.2	20
1906.82	1.17	+11.4	+11.1	+0.3	44
1906.82	1.17	+11.7	+11.1	+0.6	41
1905.01	1.26	+12.6	+ 9.0	+3.6	14
1906.98	1.33	+ 6.5	+ 7.0	−0.5	45
1889.94	1.38	+ 5.2	+ 5.5	−0.3	6
1907.10	1.45	+ 3.0	+ 3.3	−0.3	48
1907.11	1.46	+ 2.3	+ 3.0	−0.7	45
1897.80	1.65	− 2.1	− 2.3	+0.2	24

DEDUCTIONS FROM THE STUDY OF *ALGOL'S* CENTER OF MASS VELOCITY

The agreement of the above sine curve with observation furnishes strong evidence of a periodic variation in the center of mass velocity of *Algol's* eclipsing system. And the character of this variation is such as to render probable the theory that a revolution of this system in a period of 1.9 years is taking place about a center distant from it not less than 89,000,000 km. It is also probable that the orbit of the center of mass of the eclipsing pair is nearly if not quite circular, and that at least three masses are involved in the system, two of which are extremely close while the third is at a distance comparable with the earth's distance from the sun, unless the mass of the third



Velocity Curve of *Algol's* Center of Mass

body be relatively small. If the mass of the third body be not relatively small, perturbations of the elements of the eclipsing pair would naturally arise, and by such perturbations as well as by effects due to the oblateness of one or more of the stars the known variations in the period of *Algol's* eclipse may be accounted for. Tisserand has shown that a rotation of the line of apsides of the close stars in a period of 130 years, would explain the long-period term in the variations of *Algol's* light-minima if the eccentricity of the orbit be 0.12. It can also be shown that a variation of 0.10 in the eccentricity of the orbit of the close stars can give rise to variations of an hour or more in the times of light-minima. Such perturbations seem consistent with the probable character of the system, though further studies both theoretical and observational are necessary to supplement the evidence furnished by the light-variations. If, however, the above orbital motion of the close system is admitted, there must result a periodic variation in the time of light-minima with a range of ten minutes and a period equal to the orbital period of 1.9 years. That such a variation was not brought out by Chandler is not surprising, since his mean epochs were separated by intervals of from 1 to 4 years, a procedure that would probably conceal a short-period term of small amplitude. It may not be merely accidental, however, that Chandler's fifteen-year term has a period of eight times the above and a range of 7 minutes. The writer hopes in the future to be able to examine photometric observations for the existence of this two-year period.

THE ELEMENTS OF THE ORBIT OF THE ECLIPSING PAIR

In order to adduce all the data bearing upon the variations in *Algol's* light-period and to show at a glance the present condition of our knowledge of the more difficult orbital elements, Table VI has been formed.

It may be seen that little can be derived from a study of these elements at present. There seems to be no evidence of variation in $a \sin i$ greater than the limits of accuracy of the determination; and the values of the longitude of periastron are too erratic to make possible any deductions from them. There is a chance of a variation of about 0.10 in the eccentricity and if, as seems to be the case,

TABLE VI

ELEMENTS OF THE ORBIT OF THE BRIGHTER STAR OF *Algol*

Epoch	e	ω	$a \sin i$	Observers
1889.9	0.0±	....	{ 1,617,000 or 1,707,000 }	Vogel and Scheiner
1897.8	0.11	4°	1,663,000	Belopolsky
1902.9	0.14	....	1,630,000	Belopolsky
1903.9	0.09	....	1,650,000	Belopolsky
1902.5	0.13	69	1,620,000	Belopolsky
1905.0	0.07	....	1,640,000	Belopolsky
1902.7	0.05	42.5	1,694,000	Belopolsky
1907.0	0.05	21	1,600,000	Schlesinger and Curtiss

e was about 0.0 at the epoch of 1890, the period of this variation would seem to be about 15 years, or about that of Chandler's short period. If the longitude of periastron is in the neighborhood of 45°, as determined by Belopolsky from his observations of 1902–7, the variation in the light-period resulting from such a variation in e would be much greater than Chandler's 15-year period could account for. Probably then, if the variation in e is real, the true value of the element (ω) is at present nearer 0° or 90° than 45°. That no more definite deductions are possible after twenty years of spectrographic obervations of *Algol* emphasizes the need for more extensive investigation of this star.

In conclusion it is of interest to consider the bearing of further observations on the velocity-curve of the center of mass, assuming that the elements of this paper are correct. The determination of the present season will follow along the ascending limb of the curve where observations are needed. In following years the observations will alternate between the two limbs of the curve until twelve years have elapsed, when they will reach the maximum and minimum of the curve and complete its accurate determination. The importance of the determination of as many epochs as possible by each observer in a season is obvious. And when a long series of observations are combined into one epoch, corrections for the varying radial velocity of the eclipsing system's center of mass should be applied to each plate, since this term is quite comparable with that arising from the earth's orbital motion. Possibly it would now be of value to again reduce the observations already made, eliminating the varying center of mass velocity for the better determination of e and ω.

The results of this paper may be summarized as follows: The known values of the velocities of the center of mass of the eclipsing system of *Algol* are found to vary with the time in such a way as to satisfy a sine curve with a period of 1.899 years. The amplitude of this curve is 9.4 km. The velocity was a minimum at the date 1901.85. The circular orbit corresponding to this sine curve has a radius of not less than 89,000,000 km and the center of this orbit is moving with a velocity of +4.1 km in the sight-line.

The mutual attraction of the three bodies which apparently enter into the system can probably account for the variations observed in the light-period.

As a consequence of this orbital motion of the center of mass of the eclipsing pair, a variation of ten minutes in the time of light-minimum with a period of 1.9 years should be shown by photometric observations.

Examination of the published elements of *Algol* suggests a possible change in the eccentricity. But our present knowledge is too meager to permit any certain deductions regarding such possible variations.

Detroit Observatory
May 1908

NOTE ON THE WAVE-LENGTH OF $H\delta$ AND $H\epsilon$ IN THE SOLAR SPECTRUM

By J. EVERSHED

The wave-length of the hydrogen line δ given in Rowland's Preliminary Table of wave-lengths in the normal solar spectrum, viz., 4102.000, has been previously called in question, since it does not agree with measures of the line obtained from vacuum tube discharges in hydrogen nor with measures of the bright line in *o Ceti*. According to Jewell, however, the position given in the table is most probably correct, taking into consideration the complicated structure of the line, due to the presence of other absorption lines.[1]

That the line should deviate in the sun from its theoretical position in the series, and from its position in terrestrial sources, by an amount so large as 0.10 Å., seems very improbable, the more so since it is now known how very closely the ultra-violet members of the series, as far as they can be photographed at eclipses, accord with the values derived from Balmer's formula. It seemed to the writer, therefore, desirable to get some measures of the emission line in the chromosphere, where the presence of interfering lines would have practically no effect. Accordingly in May 1907 a spectrograph was arranged for photographing $H\delta$ at the sun's limb.

A preliminary difficulty presented itself in the diminishing intensity of the hydrogen lines toward the ultra-violet, and the consequent rapidly diminishing height above the photosphere at which the lines can be photographed, as bright lines, under ordinary circumstances. In the case of $H\delta$, with a tangential slit at the sun's limb one obtains a broad bright line, corresponding with the lower region of the chromosphere, and even this is easily obliterated by a slightly diffusive sky, or by unsteadiness in the image. Probably it would be possible to photograph $H\delta$ as a narrow line in the brightest prominences, but possible motion in the line of sight in these would vitiate any measures of wave-length. It was found, nevertheless, that by placing the slit slightly within the limb, the bright line is still visible, but with the

[1] *Astrophysical Journal*, **9**, 211, 1899.

narrow absorption lines superposed. This absorption line is fairly easy to measure, being free from interfering lines; and since the lines used as standards in the determinations of wave-length are due to the photospheric spectrum in the same locality as the hydrogen, motion in the line of sight due to rotation is eliminated. Recognizing, however, the possibility that the higher chromosphere might rotate at a speed differing from that of the underlying reversing layer, it was thought best to make a series of exposures on both east and west limbs, taking finally the mean values obtained from both. These mean values would still be subject to a small positive correction due to the shift of the low-level lines at the limb toward the red, discovered by Halm, which in all probability will not affect the hydrogen lines, at any rate to the same extent.

The spectrograph I employed consists of a plane grating, with 14,428 lines to the inch, and a ruled surface 3.2 inches in length. The collimator has a $3\frac{1}{4}$-inch visually corrected lens of 36 in. (914 mm) focal length; and a single plano-convex lens of 101 mm (4 in.) aperture and 213 cm (7 ft.) focus for $H\delta$ is used for the camera. The instrument is used in connection with the 12-inch Cooke photo-visual lens of this Observatory, which gives an image of the sun about 60 mm in diameter. The best results were obtained in the fourth order, notwithstanding the long exposures needed, and most of the plates obtained include, besides $H\delta$, the lines $H\epsilon$, H, and K. They are on a scale of 1 mm = 1.9 Å., approximately. Recently it has been found better to use the grating in the position to give greater magnification, as in this way the full photographic resolution can be realized with the greatest economy of light, and without increasing the length of the camera.

The results obtained from the few plates selected for measurement last year are not sufficiently numerous or accordant to give a really good value for the wave-length of $H\delta$; but they show nevertheless, I think conclusively, that the line does not differ appreciably from its theoretical position. A few measures have also been obtained from spot spectra, where the line seems always to be narrowed, and in many cases is very much weakened: these measures confirm the others in showing that Rowland's value, 4102.000, must certainly be erroneous.

In the following table I give the values of $H\delta$ separately for the

east and west limbs. The measures were made with a Hilger micrometer microscope, having a screw of 1 mm pitch, and reading to 0.01 mm, and by estimation to 0.001 mm. Each determination is a mean of two separate measures, in which the end of the spectrum toward the red was placed to the right and left respectively. The lines used as standards are the iron lines given in Rowland's table at 4100.315, 4100.901, 4101.421, 4104.288, and the line at 4103.097 attributed to silicon and manganese.

TABLE I

$H\delta$ ABSORPTION LINE

Date 1907	East Limb		West Limb	
	Latitude	Wave-Length	Latitude	Wave-Length
May 18...........	−13°	4101.88	+12°	4101.89
May 18...........	−10	.89	+ 7	.91
May 18...........	− 8	.92	− 8	.90
May 19...........	+ 8	.91	−10	.91
May 19...........	+10	.90		
May 20...........	+ 9	.88	− 8	.91
May 30...........			+14	.90

Mean, east, 4101.897; mean, west, 4101.903; mean of east and west, **4101.900**; mean width of emission line, 0.62; of absorption line, 0.29.

In spot spectra the line shows a tendency to be displaced to the violet, which in some instances is very marked. In the spot of July 16, 1907, $H\delta$ is displaced about 0.05 to the violet, while $H\gamma$ is apparently in the normal position. It is to be remembered that the absorption lines in the two cases may represent different levels in the chromosphere. In the following measures the iron lines in the spot spectra were used as standards. Any displacements therefore are relative to the spot lines, and not those of the sun. No measurable displacements were detected, however, in the reference lines of the spot spectra, compared with those of the neighboring photosphere.

Three spot spectra photographed with the 18-ft. grating spectrograph at Mount Wilson in November 1906 give respectively .	4101.897
	.883
	.839
Spot spectra photographed at the Kodaikanal Observatory:	
Large spot, 1907, June 20	4101.821
Same spot, 1907, June 22	.868
Spot of 1907, July 16	.866

The rather large deviations in the separate measures in Table I are not due to errors of measurement, but are probably partly accounted for by the disturbing effect of a bright sky on the position of the reference lines. This is almost certainly the case with the plate of May 18, latitude $-13°$ east. In this image the chromospheric lines δ, ε, H, and K are very strong as bright lines, but the Fraunhofer lines are weak, and are probably partly due to skylight. Rotation displacement will therefore affect the measures to some extent. In the mean values the west limb seems to give a slightly larger wave-length than the east, which would indicate a greater rotational speed for hydrogen compared with the reversing layer. But as the influence of the sky spectrum would tend in this direction it would be unsafe to draw this conclusion without further evidence. In the plate of May 20, however, in which the east and west spectra are photographed side by side, the evidence of a forward drift of the hydrogen and calcium over the gases of the reversing layer seemed so clear when direct measurements of the displacements were obtained, and the measures were extended to H and K, that it was decided to make a separate investigation to determine whether this was a normal condition or merely a local drift of the higher chromosphere. I give in a subsequent paper some of the results of measures made on plates in which the two limbs are photographed simultaneously.

The line *Hε* is easily photographed as a bright line, as it comes under the protection, so to speak, of the broad shading of H, but in only one instance have I found any trace of an absorption line, and this was too faint for measurement. In the measures the broad line was bisected, and the edges, which are well defined, were also measured, the mean of the two edges being used to correct the central bisections. The measures with the less refrangible end of the spectrum placed to the right and left respectively show a greater degree of accordance than those of *Hδ*, and in Table II, I retain the third decimal figure, since the mean error for each determination is well below 0.005 Å. The lines used as standards are the iron lines in Rowland's table at 3960.422, 3965.655, 3969.413, 3971.475, and 3977.891; and in one plate the aluminium line at 3961.674 was used.

Excepting the west limb spectrum of May 20, which gives abnormally large values for all the four chromospheric lines (δ, ε, H, and K),

TABLE II

Hε Emission Line

Date 1907	East Limb		West Limb	
	Latitude	Wave-Length	Latitude	Wave-Length
May 18...........	−13°	3970.222	+12°	3970.200
May 18...........	−10	.219	+ 7	.195
May 18...........	− 8	.220	− 8	.203
May 19...........	+ 8	.215	−10	.204
May 19...........	+10	.220		
May 20...........	+ 9	.213	− 8	.229
May 30...........			+14	.201

Mean, east, 3970.218; mean, west, 3970.205; mean of east and west, **3970.212**; mean width of emission line, 0.52.

the values for the west limb are all smaller than those for the east, the mean diffeernce, excluding May 20, being 0.018 Å. The displacement is in the opposite direction to that shown by $H\delta$ in Table I, but this apparently anomalous behavior of the two hydrogen lines receives a probable explanation when we consider the conditions in photographing a bright chromospheric line like ϵ, and a dark reversal of a bright line as in δ. In the former case, we have an angular separation amounting to several seconds of arc between the source of the bright line and that of the dark lines to which the measures are referred; and a slit of finite width. A consideration of the subjoined diagram will show that the displacement due to this cause may amount to half the slit-width × the ratio of the focal lengths of collimator and camera, when the bright radiation extends outward from the photosphere with uniform intensity for a distance equal to, or greater than, the slit-width.

In the diagram, *LL* represents the position of the sun's limb during an exposure, *S* is the opening of the slit greatly magnified, while the dotted line represents the upper limit of the chromospheric radiation, the photosphere being on the opposite side of *LL*. It is evident that whatever position the limb may occupy within the opening of the slit, provided it remains stationary during the exposure, the spectral images of the photosphere and chromosphere will be displaced relatively by half the slit-width, and this of course will be increased

in proportion as the length of the camera exceeds that of the collimator. Obviously a dark reversal on a broad bright line will not be subject to this displacement, as the source of the reversal is the same as the source of the reference lines. It will, however, be unsymmetrically placed on the bright line.

In the spectrograph I employed the optical parts were so arranged that the east limb was on the more refrangible side of the spectral images of the slit. The width of slit used was 0.05 mm, and the camera magnified 2.3 times: therefore, under the ideal conditions of perfect steadiness of the sun's limb represented in the diagram, and uniform intensity in the chromospheric radiation, there would be a linear displacement of $0.025 \text{ mm} \times 2.3 = 0.057$ mm, equal to 0.108 Å., with the dispersion employed. This would be in the direction which would increase the east limb values, and decrease those of the west limb. In the actual case of an unsteady image, the whole slit may be illuminated many times in succession by both photosphere and chromosphere during an exposure, and this tends to brıng the chromospheric lines to their normal positions with respect to the photospheric lines. Also the ϵ radiation does not extend uniformly to any considerable height, the effective portion of the light coming from a very low level. That the actual displacement found is only one-sixth of the value deduced above is not therefore at all surprising.

Although no significance, therefore, can be attached to the apparent displacement of $H\epsilon$ at the two limbs, the mean value of east and west will be entirely free from this source of error.

I give finally in Tale IV a comparison of the principal hydrogen lines in the sun, and the computed values from the formula $\lambda = \dfrac{an^2}{n^2-4}$ where n is the series number and a is the value of the limit of the series *in vacuo*, derived from Rowland's values of the first three lines, viz., 3647.1369. The computed values have been corrected to air, in accordance with a table by Runge.[1]

The observed values of the lines α, β, and γ are from Rowland's table; δ and ϵ are the values found above, and are subject to the small positive correction before mentioned due to pressure-shift of the reference lines. They are not, of course, definitive values, but they

[1] *Astronomy and Astrophysics*, **12**, 426, 1893.

TABLE IV

WAVE-LENGTHS OF HYDROGEN LINES

Designation	Observed	Computed	O.−C.
α....................	6563.045	6563.063	−0.018
β....................	4861.527	4861.516	+ .011
γ....................	4340.634	4340.631	+ .003
δ....................	4101.900	4101.893	+ .007
ε....................	3970.212	3970.225	− .013

show much a closer accordance with the values derived from Balmer's formula than is the case with Rowland's measures of these two lines.

SOLAR PHYSICS OBSERVATORY
KODAIKANAL, S. INDIA
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